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REPORT

ON A

SCHEME FOR SUPPLYING COMPRESSED AIR MOTIVE POWER

IN THE TOWN OF

BIRMINGHAM,

With Tables and Formulæ for calculating the Useful Effect obtained from Compressed Air, and Examples and Diagrams showing the application thereof.

BY

THOMAS ALFRED ENGLISH, C.E.,

COPENHAGEN,

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With confirmatory Report by

Professor HENRY ROBINSON,

M. Inst. C.E., F.G.S., &c., &c.

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1883.

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To the MAYOR, CORPORATION AND BURGESSES OF THE TOWN OF BIRMINGHAM.

Gentlemen,

In presenting to your notice the following Report of a Scheme for supplying Compressed Air Motive Power in your town, and in asking for your favourable consideration thereof, we would beg especially to point out the following advantages which would accrue from the introduction of this system in Birmingham in so far as it affects the prosperity and health of the town.

1. It would greatly enhance the value of property in the neighbourhood where the new power is available, and improve its rateable value.

2. The possession of such a convenient and cleanly power would attract to your town many new branches of trade requiring motive power, besides largely increasing those already in existence there, as the first cost of laying down motive power plant for each workshop or factory is so much lessened, and its working simplified and cheapened.

3. The expenditure of a large sum upon works, and the introduction into the town of new objects for the employment of capital, would give a great impulse to the trade of the town, and the special advantages afforded to manufacturers would place Birmingham in a superior position to other manufacturing places.

4. The hygienic advantages of the system would be most important, viz. :—

(*a*). A large and important abatement of the smoke nuisance, by dispensing with a great number of the smaller factory chimneys emitting smoke low down into the atmosphere of the town, from small and badly constructed furnaces in which an efficient combustion cannot be obtained.

(*b*). The introduction into the manufacturing parts of the town of large volumes of pure air, instead of the noxious vapours from chimneys.

(*c*). Improved ventilation of workshops by the exhaust air from the executive engines.

(*d*). Diminished risk of boiler explosions and damage to life and property thereby.

(*e*). The diminution of the death rate consequent upon the general improvement of the atmosphere of the town.

(*f*). A great reduction in the bulk of refuse matter, such as ashes, &c., that has to be removed from the town, or is at present thrown into the Rea.

Trusting these advantages may induce you to give your approval and support to this scheme.

We have the honour to remain,

Your obedient Servants,

T. A. ENGLISH,
C. J. HANSSEN,
JOHN STURGEON.

3, Westminster Chambers,
Victoria Street, London.

March, 1883.

SCHEME

FOR SUPPLYING COMPRESSED AIR MOTIVE POWER

In the Town of BIRMINGHAM.

INTRODUCTORY REMARKS.

Object of the scheme.

THE primary object of this Scheme is to provide economical motive power, possessing at the same time superior hygienic advantages, to take the place of the Steam Power at present employed in driving the numerous engines of small or moderate power in use in the town of Birmingham.

Compressed air the proposed power.

The power it is proposed to apply is **Compressed Air,** which can be generated economically on a large scale at a central depôt or station, by means of engines and boilers of large size provided with all the latest improvements for securing economy of fuel, the Compressed Air so generated being distributed throughout the manufacturing portion of the town in pipes or mains, just as gas and water are now supplied.

Advantages to power users.

This enables the motive power users to obtain to a large extent the advantages of the most approved economical appliances known, both in steam engines and boilers, such as could not be applied conveniently or with equal advantage to a number of separate steam engines and boilers of small size.

Central power-producing depôt.

The principle of generating motive power on a large scale at great central depôts, and therefore, economically, and distributing it throughout manufacturing districts to the various factories and workshops, has, of late, been much advocated by the highest authorities. The nearest approach to the realization of the idea is that of the Hull Hydraulic Power Company, carried out by Mr. Henry Robinson, M. Inst. C.E.; and the Gas Engine. Electricity has been proposed, but is yet in an undeveloped stage. The scope and usefulness of hydraulic power is limited to a certain kind of work, and they all impose upon the user the necessity of investing capital in new and costly plant, except in the case of entirely new works, for which new motive power engines would have to be provided in any case.

Previous attempts at same. Objections to gas-engine, hydraulic power, and electricity.

Applicability of compressed air to existing engines.

Compressed Air, on the other hand, can be applied not only for motive power, but for many other useful purposes not within the scope of the Gas Engine, Hydraulic Power, or Electricity. It has, moreover, the enormous advantage that **it can be applied to the existing engines** without involving any change of plant, **nor imposing one farthing**

of expense upon the present users, who would on the contrary be enabled to dispense with their boilers and utilize the space for other purposes, also dispensing with the stoker and engine-driver.

Pure air the only waste product.

In place of objectionable waste products, such as smoke from chimneys, exhaust steam, ashes, and condensed water, the only waste would consist of pure air, introduced into the workshops from the exhaust ports of the engines, and there would be no nuisance of dust from the stoke holes.

Saving of trouble, time, and fuel.

There would be no time lost or fuel expended in getting up steam, the Compressed Air being ever present, so that the engine could at any moment be started by opening a valve, and the air shut off when not required. No running down of steam, banking up of fires, slacking or removal of ashes.

No boiler repairs &c.

There would be no wear and tear, repairs, or renewing of boilers, fire bars, &c.; no cleaning of flues, cartage and disposal of refuse, boiler insurance, smoke nuisance fines, &c.

No explosions.

No more disastrous boiler explosions, no trouble from freezing of water pipes or bursting of steam pipes in frosty weather.

For a clear statement of the advantages of this system see extract from a Treatise on the "Transmission of Power," by Mr. Robert Zahner, C.E., of New York, at page 54 of this Report, see also the "Facts about Compressed Air," page 55.

The following example will illustrate the economy resulting from this system:—

Cost per H-P. per annum of small steam power in Birmingham.

Taking an engine indicating 10 H-P., it has been ascertained by personal investigation on the spot, that engines of that size in Birmingham burn generally not less than 16-lbs. of slack per indicated H-P. per hour, and indeed, in many cases as much as 28-lbs. (there are instances of engines of even as much as 30 H-P. consuming at that rate). Taking the consumption at the lowest figure, viz.:—16-lbs., and at 9 hours per day we have—

Slack used, 160-lbs. per hour, or 1,440-lbs. per day, say for 300 working days =say, 190 tons per annum, then we have;

Slack, 190 tons at, say, 6/-	£57	0	0	per annum
Proportion of Man's Wages, stoking, &c., say	25	0	0	,,
Repairs, depreciation, and renewal of boiler, fire bars, &c.	10	0	0	,,
Boiler insurance, smoke nuisance fines, &c.	5	0	0	,,
Interest on capital invested in boiler, &c., water rate, cartage of ashes, cleaning flues, &c.	10	0	0	,,
	£107	0	0	

Say, £100 per annum for ten H-P., or £10 per H-P. per annum, as the cost of small steam power in Birmingham.

Amount of power to be provided.

Now in the scheme at present proposed for Birmingham it is intended to provide for the delivery of 5000 indicated H-P. in Compressed Air in the town, as per calculation given at page 29. Referring to page 53 it will be found that the annual cost of producing that power is, in round numbers, about £20,000, which is equivalent to £4 per indicated H-P. per annum.

Cost per H-P. per annum of compressed air.

Selling this to the users at, say, £8 per indicated H-P. per annum (viz.: a profit of £4), the 5,000 H-P. would produce an annual profit of £20,000, or **ten per cent.** upon the capital expenditure of about £200,000 as shown by the estimates; and thus giving to the power users an average saving of fully **twenty per cent., without putting them to one farthing of expense in first cost.**

But even this result, favourable as it is, can be very considerably improved by burning, as far as practicable, all such portions of the ash-pit and other refuse of the town, as possesses the best calorific power, as a substitute for coal, in the boilers at the central air compressing station. As there would be as many as 44 large boilers employed, this plan would afford the Corporation an easy way of getting rid of a great portion of the town refuse, and save the Company a corresponding amount in the cost of coal fuel.

Cost of air-power reduced by burning town refuse in the boilers.

It may, therefore, be fairly anticipated that the actual profit realized will be not less than from *Twelve to Fifteen per cent.*, as shown by the balance sheet of estimated expenditure and income at page 53.

By reference to the list of steam users in three Wards of Birmingham, at pages 9 to 19, it will be seen that the 5000 H-P. provided is considerably under what really exists there at the present time.

The foregoing estimates are based upon the assumption that the *whole* power of the Air Compressing Engines would be expended in the supplying of these 5000 H-P. But there are many special applications in which the use of this power would prove so convenient, that the Company could in such cases command a much higher price for the power supplied.

Compressed air-power useful for many other purposes besides driving existing engines.

Thus for Builders and Contractors' Work, it would prove a most handy and convenient power. As it can be conveyed in india-rubber flexible pipes, it can be used to work winches and cranes on the top of buildings in the course of construction, in place of the present expensive steam traversing cranes; also for pile driving, working mortar mills, pumps, and other machinery, avoiding the necessity of expensive portable engines and boilers.

For builders and contractors.

It would always be ready for immediate use to drive pumps or water ejectors in case of fires, where prompt action is of greater importance than questions of cost.

For fire pumps.

It would be at hand to draw foul gases out of sump holes, drains, &c., and to supply fresh air to enable men to work therein.

Discharging noxious gases.

As Compressed Air in expanding after performance of work produces a rapid lowering of temperature (as low as 50° F. being easily attainable), this fact enables Butchers, Brewers, Fishmongers, Butter-factors, and others requiring refrigerating or cooling processes, to obtain, at trifling cost, all the advantages of artificial cooling, which have hitherto only been obtainable by either a large expenditure in ice, or the erection at great cost of complete ice making or cold air producing plant, entirely beyond the reach of the smaller tradesmen. All that is required on this new system is a small engine, in each case (which can be employed as a motive power engine for sundry purposes), the exhaust air from which produces the required refrigerating effect. As the engine in this case would perform a double function, a higher charge could be made for it than if used for motive power only.

Refrigerating.

For effecting the removal and discharge of sewage, draining cellars and low lying districts by means of Isaac Shone's Pneumatic Ejector system, as now in use at Eastbourne, Warrington, Winchester, &c., thus dispensing with pumping engines, boilers, &c., and enabling a proportionately higher charge to be made for the use of the power.

Discharging sewage.

This system also satisfactorily solves the problem of driving Tram Cars by other than animal power. The hinderance to the introduction of Com-

Driving tram cars.

pressed Air for driving Tram Cars has, hitherto, been the necessity of having a separate traction engine to each car, or air receivers charged up to excessively high pressures, to enable the car to complete its journey outwards and back to the starting point, where the receivers can be again charged up. Should the air fall short on the road, as it might do in slippery weather for instance, the car would be helpless. But, as in this case, Compressed Air would be laid in the streets along the principal car routes, it is easy to arrange means whereby power can be picked up on the route, as, for instance, by providing hose connections at convenient intervals along the air mains, by which receivers, carried on the cars themselves, may be filled up to any required pressure, by means of a donkey pump attached to the car, driven by the engines used to drive the car, and taking in its air at the main pressure and further compressing it as required; or by providing a special pipe charged to the required pressure from which the car could fill up whenever necessary. As the air pressure is thus easily renewable along the route, the necessity for large receivers charged to dangerously high pressures, or for separate traction engines no longer exists.

Ventilating, blowing organs, driving hammers, hair brushing, and other small machines.

There are also many other special applications for which more profitable rates could be charged,—such as driving hammers,—ventilating hospitals, &c., by means of air jet nozzles,—improving draught of chimneys, —supplying air for blowing organs in churches, concert halls, &c., without the use of machinery,—driving hair-brushing and other small machinery,—working pumps under water, or other machinery (such as portable rivetting, or drilling machines, &c.) in situations where steam cannot be applied, or where the exhaust steam would prove inconvenient,—and even for many domestic and other purposes, for which the easy application of such a handy power would *open up a new and wide field.*

Various domestic purposes.

For electric lighting.

Besides all these there is one important application in connection with **electric lighting** which would greatly facilitate its introduction in towns where this Compressed Air Power system is established. At present, Electric Light Companies are obliged to lay down costly plant at a Central Station, on a scale sufficient to meet an estimated demand which may or may not be ever reached, and to lay large conducting wires of considerable length. But in towns where our system is established, Compressed Air may be employed to drive small dynamo motors at convenient centres, and these can be applied anywhere from time to time as the demand increases. As the Compressed Air would not be much required during the night when the electric light is most required, nearly all the vast stored up power laid on in the streets is available for this purpose, thus overcoming many difficulties as regards distribution over large areas, avoiding the cost of many separate stations with their attendant expenses, and opening a way to the application of electricity for private house lighting.

The profit to be derived from these special applications of Compressed Air can hardly be estimated, but is certain to be considerable, and to still further increase the total annual profit.

Will be found advantageous even in large factories.

In preparing this scheme, it has been considered safer to count only upon the smaller class of engines as customers for the Compressed Air Power. But, even in large factories it is probable that it will be found more economical to drive each separate department, floor, or group of machinery

by a separate Compressed Air Engine, thus saving the power expended in driving the mass of dead weight in shafting and gearing, and in getting up and running down steam, &c., &c., which in many cases would be found a full set off against the extra cost of the Compressed Air. The convenience, cleanliness, and healthiness of the motive power, and its peculiar advantages as regards ventilation and the introduction of pure air into the workshops, would form another strong inducement for its use in large factories. It also involves another important advantage, viz., that in case of a break-down, only a small portion of the mill would be stopped, whereas on the present system the breakdown of the engine or boiler involves the stoppage of the entire mill. In the case of new mills the advantages of this system would be still more apparent, as it would save the first cost of chimney, flues, boiler setting and boilers, engine foundations, mill-dams, water connections, &c.

Demand will probably exceed supply.

Enough has now been advanced to show that the 5000 H-P. it is proposed in the first instance to provide for, is likely, indeed we may safely say, certain to be fully employed. It will, however, be seen that in the following Scheme room has been allowed for future extension to produce double the amount of power it is at present proposed to provide for.

STEAM USERS IN BIRMINGHAM.

In order to determine the position and extent of the Air Compressing Works to be laid down, it is necessary first to ascertain the present number of Steam users in the most suitable manufacturing part of Birmingham. We have selected the Wards of SAINT BARTHOLOMEW, DERITEND, and SAINT MARTIN, as affording the most promising area. The following is a list of the Steam users, and nominal horse power of each, as made out for rating purposes in those Wards.

SAINT BARTHOLOMEW'S WARD.

Name.	Situation of Premises.	Horse Power.
The Battery Co. (W. & T. Gibbins)	80, Digbeth....	102
Williams & Whitefield (*Void*)	106 ,, ...	2½
William Grice	Floodgate Street....	6
Edmund Boughton	Next 104 ,, ,, ...	14
John Holmes	Next 113 ,, ,, ...	12
Void	48 ,, ,, ...	3
T. & W. Tetley	46 ,, ,, ...	10
David Powis	33 & 34 ,, ,, ...	9½
Lloyd Bros. & Co.	25 ,, ,, ...	65

NOTE.—The premises marked VOID *are at present unoccupied.*

Name.	Situation of Premises.	Horse Power.
Arkinstall Bros.	15, Milk Street	2
S. J. Hills	,, ,, ...	16½
T. & S. Clews	6, Coventry Street	2
J. J. & H. Hossell	96 ,, ,, ...	5
Corder & Turley	Allison Street	12
John Wright....	63, Oxford Street	21
William Hinde	15 ,, ,, ...	3½
James Whitfield	39 ,, ,, ...	16
Saml. Whitfield & Sons	52 ,, ,, ...	12
T. F. Walker....	58 ,, ,, ...	6
Thomas Wells	59 ,, ,, ...	3
John Powell	74 ,, ,, ...	11
Hopkins & Son	Albert Street	9
Cund Bros.	Paternoster Row	1
Hassall & Singleton....	Park Street	5
Philemon Trueman	84 ,, ,, ...	5
Horsley Bros.	Next 69 ,, ,, ...	8
J. & W. Breedon and Booth	Fazeley Street	19
Clifford & Sons	,, ,, ...	150
Void	62 ,, ,, ...	8
William Perks & Co.	52, Dale End	16
Samuel Mason....	56 ,, ,, ...	4
William Baxter	53 ,, ,, ...	1
W. R. Deykin and Charles Preston....	2 to 6, Jennens Row	23
E. P. North	19, Bartholomew Street	4
Thomas Tebbs	48 ,, ,, ...	3
Frederick Grew	Moor Street	6
William Adams	Back, 16 ,, ,, ...	5
White & Impey	34 ,, ,, ...	8

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Name.	Situation of Premises.	Horse Power.
J. C. Holder	1, Nova Scotia Street	8
Void	21, Masshouse Lane	4
Charles Lee	18 & 19, Freeman Street	4
Hassall & Singleton....	20 to 24 ,, ,, ...	7
Mary Ann Auden	27 ,, ,, ...	2
John Keeling	28 ,, ,, ...	2
Naish & Co.	21 & 22, Coleshill Street	8
Thomas Moore	26 ,, ,, ...	4½
Thomas Yates	37 & 38 ,, ,, ...	12
George Rathbone	5 to 8, Grosvenor Street	1½
William Grice	50, Lower Fazeley Street	8
Samuel Walker	66 ,, ,, ,, ...	70
W. A. Lyndon	"Minerva Works" ,, ...	80
Banks & Hackett	,, ...	10
Henry Martin	10 & 11, Bishop Street	2
Richard Peyton	20, Banbury Street....	22
Fenby & Walker	3 to 6, Andover Street	5
Void	7 ,, ,, ...	8
Rowland Lewis	Back, 97, Bordesley Street	15
Tailby & Cooper	100 ,, ,,	34
Richard & Arthur Chamberlain	3 to 6, New Bartholomew St.	12
Void	7 & 8 ,, ,,	30
W. H. M. Blews	9 to 14 ,, ,,	12
J. B. & E. Dyson	15 & 16 ,, ,,	2½
Joseph Hill	78, New Canal Street	1
Edgar Smith	8, Engine Street	3
William Barwell	25 to 31, Pickford Street	9

Name.	Situation of Premises.	Horse Power.
Executors of Joseph Holder	2 & 3, River Street	24
Cox Bros. and Holland	4 ,, ,, ...	52
C. H. & G. J. Williams	5 ,, ,, ...	17
George Wingrove	6 ,, ,, ...	14
William Luckman	12 & 13 ,, ,, ...	28
Allen Everitt & Sons	Adderley Street	277
Corporation of Birmingham	Gas Works ,, ,,	30
William Kemp	140 ,, ,,	3
John Wilkes & Sons....	Liverpool Street	289
Stephenson, Tube & Co.	,, ,, ...	50
J. & W. Mitchell	460 to 466, Coventry Road	24
Westley & Son	485 & 486 ,, ,,	15
Matthew J. Hart	36 & 37, Great Barr Street	3½
John Pitt	122 ,, ,,	3
H. Pooley & Son	18, Heath Mill Lane	3
Hoskins & Sewell	,, ,, ...	6
Cox Bros. & Holland	Gibb Street	60
Cox Bros. & Holland	13 to 16 ,, ,, ...	18
Joseph Vann...	40 & 41, Garrison Lane ...	3
Skelding & Wright	Town Brickworks ,, ...	10
Barrows & Howl	Midland ,, ,, ...	15
Weston & Cashmore....	,, ...	3
Godfrey & Co.	73, Watery Lane	12
S. B. Whitfield	,, ,, ...	14
James Warne	56 ,, ,, ...	2½
George Page	78 ,, ,, ...	6
John Huggins	131 ,, ,, ...	3
J. Derrington	Brickyard, St. Andrew's Road	16
Wm. Henry Moore	104, Upper Trinity Street....	10
G. & W. Purser	Palmer Street	6

Name.	Situation of Premises.	Horse Power.
J. & C. Lawrence	31, Penn Street, Deritend....	8
Crofts & Crane	Allcock Street	6
Warwick and Birmingham Canal Company	27, Bowyer Street	100
John Giles & Son	New Bond Street	3
John Cartwright & Son	,, ,, ...	10
Fardon's Vinegar Company....	Glover Street	23
J. T. Bott	,, ...	6
H. & F. Shaw	,, ...	5
Hardy & Brittain	,, ...	30
Void (was the Marshfield Co.)....	,, ...	66
John Huggins	,, ...	12
Executors of John Bond	Keeley Street	26
Icke & Co., ...	Lawley Street	6
Abbott & Co.....	,, ,, ...	3
Abel Carter	Bolton Street	6
John Hands & Co.	A. B. Row	5
L. & N. W. Railway Company	Curzon Street	40
J. J. Hossell	Belmont Passage	5
Thomas Taylor	Montague Street	2
Corporation of Birmingham	,, ,, ...	10

DERITEND WARD.

Hoskins & Sewell	After 23, Charles Henry St.	10
Martin Lloyd	32 ,, ,, ,,	6
Henry Cox	57 ,, ,, ,,	16
T. A. Eaves	92 ,, ,, ,,	6
W. Richardson	93 ,, ,, ,,	2½
George Luckman	98 ,, ,, ,,	12

Name.	Situation of Premises.	Horse Power.
George Parsons	115 Charles Henry St.	2½
Henry Giles	116 ,, ,, ,,	4
H. W. Periam	118 ,, ,, ,,	12
T. J. Walford	119 ,, ,, ,,	8
Birmingham India Rubber Company	126 ,, ,, ,,	6
Thomas Wild	After 157 ,, ,, ,,	20
J. W. Higgins	Next 172 ,, ,, ,,	12
H. J. Hookham & Son	174 & 175 ,, ,, ,,	12
Executors of J. C. Onions	,, ,, ,,	4
George Twigg	28 to 30, Moseley Road	5
William Newell	26 ,, ...	4
William List	135, Moseley Street	7
W. Tonks & Sons	201 ,, ,, ...	32
Harcourt & Son	223 ,, ,, ...	10
R. G. Gumbley	84 ,, ,, ...	6
Robert Foster	49 & 51, Moseley Street	6
Henry Bralee	66 ,, ,, ...	1½
Executors of Harper	148, Cheapside	10
Breedon & Booth	153 to 157, Cheapside	24
T. & I. Gee	208 ,, ...	3½
Gibson & Birch	,, ...	7
J. Fitter	205 ,, ...	8
Henry Gomery	232 ,, ...	14
Samuel Robotham	55, 56 & 57, Bradford Street	15
C. S. Fairbank	54 ,, ,,	15
J. C. Onions, Limited	,, ,,	12
Griffiths & Browett	,, ,,	54
T. Willcox & Co.	99 & 100 ,, ,,	6
Clement, Davies & Co.	123 ,, ,,	12
Kirby, Beard & Co.	228 ,, ,,	18
Edward Cook	261 ,, ,,	18
Patent Enamel Company	288 ,, ,,	8
Henry Cooper	293 ,, ,,	75
Arthur Holden	218 ,, ,,	3
A. J. Ward	233 ,, ,,	2
Taylor Brothers	,, ,,	3½
Marshall & Sons	74 ,, ,,	8
C. J. Clarke	114 ,, ,,	3

Name.	Situation of Premises.	Horse Power.
William Garrad	Warwick Street	10
Cox, Bros. & Holland (*now Void*)	21, Alcester Street	18
Hiram Wilcox	187 ,, ,, ...	8
J. R. Boyce	25 ,, ,, ...	8
John Whitehouse	3, Green Street	32
Stokes & Co.....	56 ,, ,, ...	12
Charles Smith & Sons	Stone Yard, Deritend	9
York & Sons	7 & 8, Birchall Street	8
Sambridge & Knight....	38, Lombard Street	7
Hoskins & Sewell	51 ,, ,, ...	4
Joseph Brown	111 ,, ,, ...	12
David Kimberley	111, Emily Street	10
James Bennett	86 ,, ,, ...	3
Lane & Champion	40, William Edward Street....	4
James Tombs	48 ,, ,, ,, ...	5
W. H. Davis & Co.	Macdonald Street	18
Bonney & Draycott	,, ,, ...	15
Daniell & Arter	"Globe Works," Upper Highgate Street	30
James Steele	Salop Street	4
Hy. Richd. Clews	67, Darwin Street....	2½
Executors of Henry Holland	160 ,, ,, ...	5
N. G. Roberts	70 & 71, Stanhope Street	8
John Birch	34 ,, ,, ...	3
Josiah Pumphrey	53 & 54 ,, ,, ...	5
Chas. E. Iles	138, Highgate Street	3
John Parker	Saw Mills ,, ,, ...	6

Name.	Situation of Premises.	Horse Power.
Tay & Francis	31, Leopold Street	6
J. Whichelo	5 ,, ,, ...	3
Thomas Knight	22 ,, ,, ...	12
Samuel Heath	116 ,, ,, ...	6
J. Rowlinson	117 ,, ,, ...	6
Henry Chatwin	120 ,, ,, ...	12
Samuel Hemming	Next 122 ,, ...	12
George Woodhall	129 ,, ,, ...	2½
James Smith....	Athole Street	6
J. & T. Cox	108, Dymoke Street	5
H. V. Walker	33, Angelina Street....	3
William Sayers	Back 151 ,, ,, ...	2
Croft	,, ,, ...	6
John Ault	,, ,, ...	1
Michael Martin	1, 2 & 3, Vaughton St., South	16
S. E. Smith	5, ,, ,,	2
Charles Hufton	45 & 47, Conybere Street	3
G. & E. Edmands	36 & 37, High St., Deritend	5
Peyton & Peyton	High Street, Bordesley	52
Hoskins & Sewell	,, ,, ...	12

ST. MARTIN'S WARD.

Sarah Jackson	44, Digbeth	1½
Thomas Smithson	Back 11, Moat Row	1½
John Gardner	Back 10 & 11, Bradford St.	2
Hubert Dollman	,, ,, ,, ,,	2
W. J. Lawrence	Back 20 ,, ,,	6
Thos. Jones & Son and Evans & Co.	31 & 32 ,, ,,	16
T. H. Eves	312 ,, ,,	16
Burbidge & Taylor	,, ,,	3

Name.	Situation of Premises.	Horse Power.
Samuel Taylor	Mill Lane	12
W. & T. Avery	,, ,, ...	12
George T. Tonk	62, Rea Street	6
Thomas Henn	82 ,, ,,	32
John Shepherd	Cheapside	4
Richard Ashton	36 to 39 ,, ...	6
W. C. B. Cave	Balsall Street	3½
William Taylor	Moseley Street	20
A. W. Robinson	27, Dean Street	3
Thos. Priest & Son	179, Gooch Street	14
W. B. Palethorpe	181 ,, ,, ...	1½
William Reaney	229 ,, ,, ...	12
Edward Fisher	238, Sherlock Street	2
William Hall	224 ,, ,, ...	2½
E. W. Buller	152 & 154 ,, ...	12
M. J. Rice & Co.	54 to 60 ,, ...	5
W. Gosling	40 & 42 ,, ...	2
Fredk. Rencher	7, Macdonald Street	4
James Humphries	78 ,, ,, ...	1
Gates & Baggott	89 & 90 ,, ,, ...	3
William Judge	54, Bissell Street	2
Elizabeth Gilbert	61, ,, ,, ...	12
Henry Tongue	Court 21 ,, ...	½
Albert Phillips	10 & 11, Rea Street, South	5
E. Atkin & Sons	18 ,, ,, ,,	28
Chas. Hy. Pugh	,, ,, ,,	10
Nelson Jones and Alfred Jones	,, ,, ,,	3
John Whitehouse	Court 1, Barford Street	12
William Boyce	97 & 98 ,, ,, ...	5
Ellis & Tebbitt	115 & 117 ,, ,, ...	3

Name.	Situation of Premises.	Horse Power.
Eliza Auster	11 to 13, Barford St. South	10
The Birmingham Syphon Company	12, Bishop Street South	2½
Isaac Henn	Skinner Lane	6
Fredk. Davis	Back 31, Bishop Street	5
William Andrews	Next 34 ,, ,, ...	7
Hannah Gardner	Saw Mills ,, ,, ...	16
	Next 268 ,, ,, ...	8
William Phillips	70, Lower Essex Street	20
H. J. Sims	71 ,, ,, ...	18
The Corporation of Birmingham	Public Baths, Kent Street....	12
James Smith	118, Bristol Street	2
E. W. Cotterill	West End Brewery, Bristol Street	3
William Street	77, Hope Street	1½
James Clarke	28, Benacre Street	1½
J. & O. C. Hawkes	125 to 129, Bromsgrove St.	30

The above figures give the *nominal* horse-power of the engines as estimated for rating purposes in Birmingham, and the actual indicated horse-power may therefore be taken as about three times the amount given in these tables.

Analysing the above tables we find there are :—

164	Engines varying from	½	to	10 H.P., with a total of	710 H.P. nom.
59	,, ,,	11	to	20 ,, ,,	843½ ,,
15	,, ,,	21	to	30 ,, ,,	393 ,,
6	,, ,,	32	to	50 ,, ,,	220 ,,
10	,, ,,	52	to	100 ,, ,,	574 ,,
4	,, ,,	102	to	289 ,, ,,	818 ,,
				Total	3,558½

Assuming that of these, only engines up to 30 H.P. nom., would be likely to use the Compressed Air Power, we then have :—

For 10 H.P. and under,	710	H.P. nom.,	yielding say	2,130	H.P. ind.
,, 20 ,,	843½	,,	,,	2,529	,,
,, 30 ,,	393	,,	,,	1,179	,,
Total indicated H.P. of engines of a size to work with most advantage by Compressed Air				5,838	,,

It must, however, be borne in mind that the above represent only the field now actually open to us, in the engines now in use; and that the existence of such a convenient and cheap power ready laid on in the streets, is likely to attract many more manufacturers requiring motive power to the neighourhood of the Compressed Air mains. There are also the many additional purposes and new demands created owing to the peculiar adaptability of this power to various ends, as referred to at pages 8 and 9, which will probably at least double the already existing field.

DESCRIPTION OF THE PROPOSED WORKS.

Amount of power to be provided.

In view of the existing requirements of the districts to be dealt with, as shown in the preceding chapter, it is proposed to provide machinery and plant capable of delivering 5000 indicated horse-power in compressed air, and at the same time to provide room for extension to double that amount.

Site for works.

The site selected as most suitable for the works is a piece of land belonging to the Birmingham and Warwick Canal Company, situated on the canal side and facing Sampson Road North and Henley Street. This land has been offered on favourable terms, including the right of using the canal water, and discharging the condensed water from the engines back into the canal, and it affords special facilities for the supply of coal and other stores by canal.

Machinery and plant at works.

Upon one half of this site it is proposed to erect four air compressing engines driven by compound condensing steam engines, giving a total of 8400 indicated horse-power (which it will be seen from the following calculation will be sufficient to produce the 5000 horse-power required to be delivered), and forty-four Cornish or Lancashire boilers fitted with Jucke's furnaces and self acting stokers, together with chimney, air purifying apparatus, and the necessary buildings and offices, as shown on Plan No. 1.

Air purifying apparatus.

Before entering the air compressing cylinders the outer air will be passed through an air filtering and purifying apparatus by which it will be cleared of soot, dust, and other impurities, in order that it may reach the consumers in a thoroughly pure state.

Proposed working pressure of Air.

The Air pressure to be delivered has been fixed at a minimum of 45 lbs. effective, or 59·7 lbs. absolute, as being sufficient to cover the majority of cases, and more economical of production than a higher pressure. In the few exceptional cases, however, where the existing engines work at a higher steam pressure, a slight alteration in the gearing or pullies connecting to the main driving shaft, so as to run the engine at a higher speed,

would enable the lower Air pressure to carry the load. Where such alteration is not possible or convenient, the bore of the cylinder may be increased, or even a new cylinder introduced of larger bore, at very slight cost.

Compressed air mains.

From the delivery branches of the air compressors a compressed air main, 30 in. diameter will be carried along Henley Street, branching into two mains of 24 in. diameter, passing through Sampson Road North, and Stratford Street. The mains then divide into various branches, passing through Sandy Lane, Fazely Street, Floodgate Street, Bradford Street, Bromsgrove Street, and other principal streets, with smaller branches in different directions, as shown on Plan No. 2.

Pressure in mains.

The maximum pressure in the mains would be 50 lbs. per square inch, and their strength would be such as to stand a test pressure of 300 lbs. per square inch. Any risk of damage from the bursting of a pipe would be thus absolutely prevented, as the engine power would not be sufficient to raise the pressure above the normal 50 lbs., the sudden and uncontrollable increase of pressure which is the usual cause of boiler explosions not being possible in this case.

Absolute safety of mains.

Accessibility of mains.

These mains would be laid in the streets at not more than three feet below the surface, so as to be easily accessible, and not to interfere with existing pipes and mains, sewers, &c.

Mains arranged so that any section may be shut off for repairs without interrupting supply.

The net work of mains would be so connected together that in case of accident to any pipe, or stoppage for repairs, the air supply can be passed along temporarily through other branches, the portion under repair being shut off by stop valves provided for the purpose, so as not to interrupt or interfere with the supply.

Re-heating the compressed air by waste heat, &c.

On reaching the consumers' premises, the compressed air, wherever practicable, would be heated by passing the air through coils subjected to the waste heat from a flue, or by any other convenient mode of heating.

Air receivers.

Storage reservoirs or receivers for the compressed air may also be applied near to the air driven engines.

Measurement of air supplied.

Before entering the air driven engine the quantity of air supplied would be measured by a suitable air meter, or in the engine itself, by a counter registering the speed and average point of cut-off and expansion.

The detailed estimates, commencing at page 34, will give the fullest information as to the nature of the proposed works and plant.

Before proceeding to investigate mathematically the engine power required, and useful effect obtained, it will be necessary to inquire into the probable losses in transmission through the mains by friction and leakage. This has been recently investigated by M. Stockalper, Engineer-in-Chief of the St. Gothard tunnel works, and by Professor Unwin, and we cannot do better than give the following extracts from their papers :—

(*From "Revue Universalle de Mines." Vol. vii. pp.* 257—281).

LOSS OF PRESSURE IN TRANSMITTING POWER TO A DISTANCE BY COMPRESSED AIR,

BY E. STOCKALPER.

Loss of pressure in transmission—Stockalper.

As Acting Engineer-in-Chief, at the Göschenen, or northern end of the St. Gothard Tunnel, the author availed himself of the opportunity to make practical trials upon the above subject, on the great length of air-main and

St. Gothard Tunnel, compressed air-mains, &c.

at the high pressure of air employed for the execution of the work. The air-main consisted of cast iron pipes 7·87 inches diameter, extending 15,100 ft. or 2·86 miles in from the tunnel mouth, and then of wrought iron pipes 5·91 in. diameter extending 1,700 ft. or 0·32 miles further. All had flanged joints, bolted together with india-rubber rings between. The velocity of the compressed air through the main, or the volume delivered per second, was ascertained by counting the strokes of the compressors, their delivery per stroke having previously been determined. The pressures in the air-mains were observed by means of Bourdon gauges, which could be read to $\frac{1}{10}$ Atmosphere. The observations were made while three different conditions of steady flow through the main were continuously maintained for about half an hour each, by altering either the working of the compressors or the discharge through the cocks at the inner end of the main. Reduced to atmospheric pressure and a temperature of 0° C. or 32° F., the volume of air flowing through the main under the three conditions were 32, 22, and 18 cubic ft. per second. The results of the observations are shown in the accompanying table.

Results of Stockalper's experiments at St. Gothard Tunnel.

Observations on Loss of Pressure in Compressed Air-Mains at St. Gothard's Tunnel, 17th December, 1878.

Condition of Flow.	Volume of Air per Second reduced to Atmospheric Pressure and 32° F. temperature.	Air Main. Length.	Air Main. Diameter.	Darcy's Values, per Co-efficient a.	Mean Temperature Inside Air-Main.	Mean Density of Compressed Air (Water = 1·000). δ	Volume per Second of Compressed Air of Mean Density δ. q	Observed Pressures. At mouth of Tunnel.	Observed Pressures. At 15,100 feet from Tunnel Mouth.	Observed Pressures. At 16,800 feet from Tunnel Mouth.	Actual Loss of Pressure.
Mean Vel. in ft.	Cub. ft.	Feet.	Inches.		F.		Cub ft.	Atmo.	Atmo.	Atmo.	Atmo.
19·32	33·056	15,100	7.87	5·7855	70°	·00650	6·534	5·6	5·24	...	0·36
I.											
37·14		1,700	5.91	25·3195	80°	·00603	7·063	...	5·24	5·00	0·24
16·3	22·002	15,100	7.87	5·7855	70°	·00514	5·509	4·35	4·13	...	0·22
II.										*	
...		1,700	5.91	25·3195	80°	·00482	5·863	...	4·13	4·06	0·07
15·58	18·364	15,100	7.87	5·7855	70°	·00449	5·262	3·84	3·65	...	0·19
III.											
29·34		1,700	5.91	25·3195	80°	·00423	5·580	...	3·65	3·54	0·11

* There was probably some error in observation of this pressure, making the loss too small.

Application of Darcy's formula for water to compressed air.

Considering Darcy's the best of the many formulæ and tables for the flow of water through pipes, owing to their close correspondence with observed results, as well as to their simple form and convenience for calculation, the author investigates their adaptation to the case of air, and demonstrates on assumption which he justifies, that the theoretical loss of pressure in air-mains may be expressed as in water mains by the formula:

$$J = a\, q^2\, \delta \text{ (for metre measure).}$$

$$J = \frac{1}{2871 \cdot 0667}\, a\, q^2\, \delta = 0{\cdot}00034831\, a\, q^2\, \delta \text{ (for feet).}$$

Where J is the loss of pressure, that is the loss of head in metres (feet), height of water column (or by 2nd rule lbs. per sq." per foot run) for each

metre forwards along the main; δ is the mean density of the comp. air, taking water = 1; q is the volume of the comp. air at the mean density δ flowing through the main per second in cubic metres (or cub. ft.), and a is Darcy's co-efficient for water deduced from his experiments; this co-efficient is a function of the pipe dia. D, and is given by the empirical formula (where D is taken in metres in each case).

$$a = \frac{8{\cdot}2423}{D^5} \times (0{\cdot}000507 + \frac{0{\cdot}00001204}{D})$$

A table is reproduced of 68 diameters, ranging from 0·01 up to 1·00 Metre (0·39 up to 39·37 in.) with the corresponding values of the co-efficient a for water, ranging inversely from 58,395,000·0 down to 0·00168275, and passing through unity at a diameter of about 0·28 metre. In other words the loss of pressure in an air main may be calculated on the supposition, that it is water instead of air which is flowing through the pipes at the same velocity, and the loss so ascertained for water has then only to be reduced in the proportion of relative densities of the air and of water, the author's experiments having satisfied him, that for all practical purposes the same co-efficient a may be applied for air, as is given by Darcy for water.

Loss of head by friction proportionate to the density of the fluid.

The calculated results arrived at by this formula vary however, from 25 to 58 p. c. in excess of the observed actual loss of pressure given in the table (foregoing), the discrepancy is ascribed by the author to certain disadvantages inseparable from the circumstances under which his experiments were made. A still greater excess marks the calculated results which he also tabulates for compression, from the formulæ of Girard, D'Aubuisson, Pecqueur, Morin, Arson, and Weisbach, confirming Prof. Colladon's experiments in 1852, which showed that the co-efficients adopted were about *twice too high.*

Actual loss of head in practice less than theoretical loss.

The temperature inside the air-main at various points of its length were observed on several different days, the velocity of flow varying from 13 to 39 feet per second, and the pressure from 3 to 6 atmospheres. They were found to remain practically constant for each individual point, and to be about 3° C. or 5° F. below the constant external or tunnel temperature at that place. (*See the minutes of proceedings of the Institution of Civil Engineers, volume* 63, *from which this extract is taken.*)

Temperature inside main practically constant and below external temperature.

Extract from Professor UNWIN'S, (B.S., M.I.C.E.,) *Paper in the Minutes of Proceedings of the Institution of Civil Engineers* (*volume* 63) *on the*

CO-EFFICIENT OF FRICTION OF AIR FLOWING IN LONG PIPES.

Unwin's formula agrees with Stockalper's experiments.

Co-efficient diminishes with an increase in the diameter of the pipe. Table by M. Stockalper agrees well with the formula:

$$\zeta = 0{\cdot}0027\ (1 + \tfrac{3}{10d})$$

this would give $\zeta = 0{\cdot}00393$ for the larger 0·656 ft. (or 7·87 in.) pipe in M. Stockalper's Table, and $\zeta = 0{\cdot}00435$ for the 0·492 ft. (or 5·91 in.) pipe, which again agrees with experiments on $2\frac{3}{16}$ in. tubes of the pneumatic system of Messrs. Culley and Sabine, who found a co-efficient of 0·007, calculating by the above rule $\zeta = 0{\cdot}0071$ almost identically the same.

Also Culley and Sabine's.

Weisbach gives co-efficients ranging from 0·012 to 0·028 or values from 4 to 7 times as great as those obtained by M. Stockalper. Weisbach's ex-

periments were made on small tubes about 2 metres long, at velocities of 80 to 490 ft. per second, and, therefore, the results do not merit great confidence. Still if the very small diameter be allowed for, they diverge much less from M. Stockalper's result than they appeared to do at first. Weisbach too high.

The table here contains a comparison.

Comparison of results by calculation and by experiment.

	Diameter of Tube.	ζ by Experiments.	ζ by Calculation. Formula as above.
Brass and Glass Tubes ...	0·400 in.	0·014 to 0·027	0·027
Ditto	0·564 ,,	0·012 to 0·026	0·020
Zinc Tube	0·960 ,,	0·013 to 0·023	0·013

Investigation of Engine Power required and useful effect obtained.

In order to ascertain the loss of power in compressing and distributing air under the conditions required, we have made the following calculations, showing the useful effect to be obtained from compressed air under different conditions of working, viz., with heat applied in different ways at the consumers' premises, without heat so applied, and with and without expansion. We have also given in full the calculation of the engine power, &c., required for the proposed works.

The theoretical amount of Power (that is the power independent of friction, leakage, resistance of valves, &c.), necessary to compress a given Volume of Air by isothermal Compression is found by the formula

$$W_t = [(\frac{1 + \log_e R}{R} \times P) - A] \times V_1 \ldots . (1)$$

where

W_t = the work performed by isothermal compression. Work performed in compressing given volume of air isothermally.

R = the ratio of compression = absolute end-pressure divided by the absolute pressure of the atmosphere.

P = pressure in the receiver = end-pressure in compressing cylinder.

V_1 = volume traversed by the compressing piston.

A = the back pressure of the atmosphere = 14·7 lbs. per sq. in.

If it be desired to know the amount of power expended in compressing *one* cubic foot of air of 45 lbs. pressure per sq. in. above atmosphere = 59·7 lbs. total pressure, Example—one cubic foot to 45lbs. effective isothermal compression.

then

$R = \frac{59·7}{14·7} = 4·0612.$

$\log_e R$, or the hyperbolic log. R = 1·4015.

P = 59·7 lbs. pr. sq. in. = 8596·8 lbs. per. sq. ft.

V_1 is, for isothermal compression, inversely as the pressure and

= R × the number of cub. ft. compressed air produced

= 4·0612 × 1 cub. ft. = 4·0612 cubic feet.

$A = 14{\cdot}7$ lbs. per sq. in, $= 2116{\cdot}8$ lbs. per sq. ft.

$$W_t = [(\tfrac{1 + 1{\cdot}4015}{4{\cdot}0612} \times 8596{\cdot}8 \text{ lbs.}) - 2116{\cdot}8 \text{ lbs.}] \times 4{\cdot}0612 \text{ cub. ft.}$$
$$= [(0{\cdot}5913 \times 8596{\cdot}8) - 2116{\cdot}8] \times 4{\cdot}0612 \text{ cub. ft.}$$
$$= 2966{\cdot}7 \text{ lbs.} \times 4{\cdot}0612 \text{ cub. ft.}$$

Therefore

$W_t = 12048$ *foot pounds.*

Sources of loss.

To find the amount of steam power necessary to compress a given amount of air, it is necessary to consider the losses caused by friction, leakage, and heating of the air.

In consequence of the high speed and large diameter of compressing cylinders we propose to use, we cannot expect to cool the central portion of the air, but only that portion of the air close to the cylinder sides; we therefore take the theoretical power as that due to adiabatic compression, but friction and leakage as due to isothermal compression.

Work done by adiabatic compression.

By adiabatic compression the mean forward pressure is found, by the formula given by Prof. COTTERILL (*Steam Engine as a Heat Engine*, page 339) where for adiabatic compression of air $n = \gamma = 1{\cdot}41$.

$$P_m = \frac{\gamma}{\gamma - 1} \times \frac{P_1}{r} - \frac{1}{\gamma - 1} \times P_2 \quad - \quad - \quad - \quad - \quad (2)$$

Where

P_m = the mean forward pressure per sq. in. (absolute).

P_1 = the pressure resulting from compression = 59·7 lbs. per sq. in. = 8596·8 lbs. per sq. ft.

P_2 = the pressure of the atmosphere = 14·7 lbs. per sq. in. = 2116·8 lbs. per sq. ft.

γ = 1·41 (a number on which the velocity of sound depends, irrespective of any special theory of heat, found by experiment to have this value for air and other simple gases).

$$= \frac{\text{Specific heat of air at constant pressure}}{\text{Specific heat of air at constant volume}} = \frac{188{\cdot}4}{130{\cdot}2} = 1{\cdot}41.$$

r = ratio of compression, the volume of air to be compressed at 14·7 lbs. pressure and 60° F. being, as in the former case, 4·0612 cub. ft., the resulting volume is found in the following way:—

Temperature due to compression = T_1

$$= \left(\frac{\text{ultimate pressure}}{\text{initial pressure}}\right)^{0{\cdot}29} \times \text{absolute initial temperature}$$
$$= \left(\frac{59{\cdot}7}{14{\cdot}7}\right)^{0{\cdot}29} 521°. \quad \text{Log. } T_1 = 0{\cdot}29 \text{ log. } 4{\cdot}0612 + \text{log. } 521°.$$

Temperature = 782·3° F.

Rise of temperature = 782·3 − 521·0 = 261·3° F. 261·3 + 60 = 321° F.

$$\text{Resulting volume} = \frac{14{\cdot}7 \text{ lbs.}}{59{\cdot}7 \text{ lbs.}} \times \frac{4{\cdot}0612 \text{ cub. ft.} (782{\cdot}3° - 28°)*}{521° - 28°}$$
$$= 0{\cdot}246 \times 6{\cdot}213 = 1{\cdot}53 \text{ cub. ft.}$$

$$\text{Ratio of compression} = \frac{4{\cdot}0612}{1{\cdot}53} = 2{\cdot}654.$$

---

* If the standard volume of these calculations were taken at 32° F. the changes of volume would be proportional to the absolute temperature, but if taken at 60° F. 60° − 32° = 28° has to be deducted from all the absolute temperatures.

Therefore

$$P_m = (\tfrac{1{\cdot}41}{0{\cdot}41} \times \tfrac{59{\cdot}7}{2{\cdot}654}) - (\tfrac{1}{0{\cdot}41} \times 14{\cdot}7 \text{ lbs.})$$
$$= (3{\cdot}439 \times 22{\cdot}49) - (2{\cdot}439 \times 14{\cdot}7 \text{ lbs.})$$
$$= 77{\cdot}346 - 35{\cdot}843 = 41{\cdot}498 \text{ lbs. per sq. in.—(}\textit{See}\text{ diagram of compression.)}$$

Mean effective pressure $= 41{\cdot}498 - 14{\cdot}700 = 26{\cdot}798$ lbs. per sq. in.
$= 26{\cdot}798 \times 144 = 3859$ lbs. per sq. ft.

Total work in compressing adiabatically.

Total power exerted in compressing 4·0612 cub. ft. of air adiabatically = 4·0612 cub. ft. × 3859 lbs. per sq. ft. = 15672 ft. lbs.

Friction and other retarding forces.

Assuming friction, leakage, and resistance of valves, to be about 24 per cent.,* in addition to the load, then each foot pound in the compressor requires 1·24 ft. lbs. steam pressure.

Friction due to 12048 ft. lbs. = 12048 × 0·24 . .	2892 ft. lbs.
Total power required for 1 *cub. ft. compressed air*	18564 ft. lbs.

Loss caused by friction in mains.

The loss in distribution caused by friction in the mains, can of course only be calculated approximately, by estimating the average quantity of air going through each pipe. By doing this and calculating the friction according to M. Stockalper's rule we find for instance for the 20 in. main going through Bradford Street, the total quantity of air delivered per second from the compressing works is 247 cub. ft. = 7 cub. metres. The pipes from Stratford Street branch off in three principal directions, of which about 35 per cent. will go to the northern part of the district, 25 per cent. to the southern part, and the remaining 40 per cent. through the 20 in. main in Bradford Street, constantly supplying air to the minor streets. Therefore, 2·8 cbm. air will pass through the first portion of this 20 in. main per second; the total length from the compressing works to the end of the district is 6000 feet = about 1830 metres; the quantity of air going through the main is constantly decreasing, until at the end there will of course pass none at all; so that the average quantity may be taken as half of the initial quantity = 1·4 cbm. The friction is then found from the formula

$$J = 1830 \times q^2 \times \delta \times a.$$

Where

J = loss of head, in metres height of water column.

δ = density of compressed air compared with water.
$= 4{\cdot}06 \times 0{\cdot}0013 = 0{\cdot}00528.$

q = volume of compressed air at the density 0·00528 flowing through the main per sec. = 1·4 cub. metres.

a = Darcy's co-efficient for water $= \frac{8{\cdot}2428}{D^5} \times (0{\cdot}000507 + \frac{0{\cdot}00001294}{D})$
where D = diam. of pipe in metres = 0·508.
$= \frac{8{\cdot}2428}{0{\cdot}508^5} \times (0{\cdot}000507 + \frac{0{\cdot}00001294}{0{\cdot}508}) = 95{\cdot}84 \times 0{\cdot}0005325 = 0{\cdot}05104.$

Therefore

$$J = (0{\cdot}05104 \times 1{\cdot}4^2 \times 0{\cdot}00528 \times 1830) = 0{\cdot}967 \text{ metres.}$$

The effective pressure = 45 lbs. per sq. in. = 31·6 metres head of water.

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* According to Sir F. Bramwell, in the Mekarski Air Compressors at Chautenay, only 18 per cent. of the gross indicated H.P. of the engines was absorbed in friction of the engine, friction of the compressing pumps, and working the condenser air-pump. (See *Engineering*, vol. xxxiv., page 258.)

The loss due to friction is, therefore, for this whole length of 6000 feet.

$$\frac{100 \times 0{\cdot}967}{31{\cdot}6} = 3{\cdot}06 \text{ per cent.}$$

To allow for all contingencies, however, an average loss of 5 per cent. is reckoned for friction in the mains, though we believe that in practice it will be found much less.

Loss by friction in the mains, therefore - - - 5 per cent.
Loss by leakage in the mains is estimated at - - 10 ,,
Loss by friction and wire drawing in the consumer's engine and service pipes- - - - - - 5 ,,

Total loss before reaching driven engines.

The compressed air will, therefore, on the average, before it comes to act in the driven engine, be reduced 10 per cent. by friction, from 45 lbs. to 40·5 lbs. per sq. in. and 10 per cent. by leakage, or 1 cub. ft. is reduced to 0·9 cub. ft.

Let us now consider the power given out by various ways of using the compressed air at the driven engine.

Useful effect obtained when the compressed air is heated to 320° F. at driven engine, and fully expanded.

Case 1. When the air is heated to 320° F. and expanded to atmospheric pressure. Absolute initial temperature = 781°. The average pressure is found from equation (2) page 24.

$$P_m = \frac{\gamma}{\gamma-1} \times \frac{P_1}{r} - \frac{1}{\gamma-1} \times P_2$$

Where, as in the former case

$$\frac{\gamma}{\gamma-1} = 3{\cdot}439$$
$$\frac{1}{\gamma-1} = 2{\cdot}439$$
$$P_2 = 14{\cdot}7 \text{ lbs.}$$
$$P_1 = 40{\cdot}5 \text{ lbs.} + 14{\cdot}7 \text{ lbs.} = 55{\cdot}2 \text{ lbs.}$$

We have only to find r = ratio of expansion. The volume of the compressed air becomes by being heated from 521° to 781° = 260°

$$\text{initial volume} = 0{\cdot}9 \text{ cub. ft.} \times \frac{781° - 28°}{521 - 28}$$
$$= 0{\cdot}9 \times 1{\cdot}5274 = 1{\cdot}3746 \text{ cub. ft.}$$

T_1 = temperature of the expanded air $\left(\frac{14{\cdot}7}{55{\cdot}2}\right)^{0{\cdot}29} \times 781°$.

Log T_1 = 0·29 log. 14·7 − 0·29 log. 55·2 + log. 781. T_1 = 532·12 = 71° F.

Volume of the expanded air

$$= \frac{55{\cdot}2}{14{\cdot}7} \times 1{\cdot}3746 \text{ cub. ft.} \times \frac{532 - 28°}{781° - 28}$$
$$= 5{\cdot}162 \times 0{\cdot}67 = 3{\cdot}458 \text{ cub. ft.}$$

Ratio of expansion = $r = \frac{3{\cdot}458 \text{ cub. ft.}}{1{\cdot}3746 \text{ cub. ft.}} = 2{\cdot}516$.

Then

$$P_m = \left(3{\cdot}439 \times \frac{55{\cdot}2 \text{ lbs.}}{2{\cdot}516}\right) - (2{\cdot}439 \times 14{\cdot}7) \text{ lbs.}$$
$$= (3{\cdot}439 \times 21{\cdot}94) - (2{\cdot}439 \times 14{\cdot}7).$$
$$= 75{\cdot}45 \text{ lbs.} - 35{\cdot}85 \text{ lbs.} = 39{\cdot}60 \text{ lbs.}$$

Average effective pressure = 39·60 lbs. − 15 lbs. = 24·60 lbs.

Loss by clearance and back pressure in driven engine.

With 8 per cent. loss by clearance and back pressure, the effective pressure becomes 24·60 × 0·92 = 22·63 lbs. per sq. in. = 3258·7 lbs. per sq. ft.—*see* Diagram of Expansion.

The effective volume is 0·96 of the total volume = 0·96 × 3·4578 = 3·320 cub. ft.

Power given out by the air = 3258·7 lbs. × 3·320 cub. ft. = 10818·7 ft. lbs.

Useful effect = $\frac{10818{\cdot}7 \times 100}{18564}$ = 58·3 per cent.

Case 2. When boiling water is available for heating the compressed air. Useful effect when boiling water is used to heat air at driven engine.

Initial temperature in the cylinder, 461° + 212 = 673° absolute.

Initial volume per cub. ft. = 0·9 cub. ft. $\times \frac{678-28}{521-28} = \frac{0·9 \times 645}{493} = 1·1775$ cub. ft.

Temperature of the expanded air = $\left(\frac{14·7}{55·2}\right)^{0·29} \times 673° = T_2$

Log. $T_2 = \bar{1}·83336 + 2·82802 = 2·66138$; $T_2 = 458·5° = -2·5°$ F.

Volume of the expanded air $\frac{55·2}{14·7}$ lbs. $\times 1·1775 \div \frac{673°-28°}{458·5°-28°}$

$= 4·4216 \times \frac{430·5}{645} = 2·9512$ cub. ft.

Ratio of expansion = $r = \frac{2·9512}{1·1775} = 2·506$.

Then:

$$P_m = (3·439 \times \tfrac{55·2 \text{ lbs.}}{2·506}) - (2·439 \times 14·7 \text{ lbs}).$$
$$= (3·439 \times 22·025) - 35·85 = 75·74 - 35·85 = 39·89 \text{ lbs.}$$

Mean effective pressure = 39·89 − 15 lbs. = 24·89 lbs. per sq. in.

With 8 per cent. loss by clearance and back pressure, 24·89 lbs. × 0·92 = 22·90 lbs. per square inch = 3297·5 lbs. per sq. ft.

Effective volume = 0·96 × 2·9512 cub. ft. = 2·833 cub. ft.

Power given out by the air:

3297·5 lbs. per sq. ft. × 2·833 cub. ft. = 9342·0 ft. lbs.

Useful effect = $\frac{9342·0 \times 100}{18564} = 50·3$ per cent.

Case 3. When the air is used expansively without reheating, whereby intensely cold air is exhausted, which may be used for making ice, &c. Useful effect without reheating, but with full expansion producing intense cold.

Initial temperature in the cylinder = 521° (absolute) = 60° F.

Initial volume per cub. ft. of air on reaching the driven engine = 0·9 cub. ft.

Temperature of the expanded air = $\left(\frac{14·7}{55·2}\right)^{0·29} \times 521° = T_2$.

Log. $T_2 = \bar{1}·83336 + 2·71684 = 2·55020$. $T_2 = 355°$ (absolute) = −106° F.

Volume of the expanded air = $\frac{55·2}{14·7} \times 0·90$ cub. ft. $\times \frac{355-28}{521-28} = 3·379 \times \frac{327}{493} =$ 2·242 cub. ft.

Ratio of expansion = $\frac{2·242}{0·9} = 2·49$.

$$P_m = (3·439 \times \tfrac{55·2}{2·49}) - (2·439 \times 14·7) = 76·22 - 35·85 = 40·37 \text{ lbs.}$$

Mean effective pressure = 40·37 − 15 lbs. = 25·37 lbs. per sq. in.

With 10 per cent. loss by clearance and back pressure:

= 25·37 × 0·90 = 22·83 lbs. per sq. in. = 3287·5 lbs. per sq. ft.

Effective volume = 0·96 × 2·242 = 2·152 cub. ft.

Power given out by the air:

= 3287·5 lbs. per sq. ft. × 2·152 cub. ft. = 7074·5 ft. lbs.

Useful effect: $\frac{7074·5 \times 100}{18564} = 38·1$ per cent.

Case 4. When the air is re-heated to the temperature of boiling water, but instead of expanding down to atmospheric pressure the driven cylinder is filled so far that the terminal pressure becomes 26 lbs. absolute = 11·3 lbs. above atmosphere. Useful effect when the air is reheated with boiling water, but only expanded to 26 lbs. absolute.

Initial temperature as in Case 2. = 461° + 212 = 673° absolute.

Initial volume = 0·9 cub. ft. $\times \frac{678-28°}{521-28°} = 0·9$ cub. ft. $\times \frac{645°}{493°} = 1·1775$ cub. ft.

Terminal temperature = $\left(\frac{26·0}{55·2}\right)^{0·29} \times 673° = T_2$.

log. $T_2 = 0·29$ log. 26·0 − 0·29 log. 55·2 + log. 673.

$= \bar{1}·90518 + 2·82802 = 2·73320$. $T_2 = 541° = 80°$ F.

Volume of the expanded air:

$$= \frac{55{\cdot}2 \text{ lbs.}}{26{\cdot}0 \text{ lbs.}} \times 1{\cdot}1775 \times \frac{541° - 28°}{678° - 28°} = \frac{33344}{16770} = 1{\cdot}9883 \text{ cub. ft.}$$

Ratio of expansion $= r = \frac{1{\cdot}9883}{1{\cdot}1775} = 1{\cdot}6886$; cut off about 0·6.

Then

$$P_m = (3{\cdot}439 \times \frac{55{\cdot}2 \text{ lbs.}}{1{\cdot}6886}) - (2{\cdot}439 \times 26 \text{ lbs.}).$$
$$= (3{\cdot}439 \times 32{\cdot}69) - (2{\cdot}439 \times 26).$$
$$= 112{\cdot}42 - 63{\cdot}413 = 49{\cdot}01.$$

Mean effective pressure = 49 lbs. − 15 lbs. = 34 lbs. per sq. in.

With 8 per cent. loss of pressure for clearance and back pressure: =34 lbs. × 0·92=31·28 lbs. per sq. in. = 31·28 × 144=4504 lbs. per sq. ft.

Effective volume 0·96 × 1·6886 cub. ft. = 1·621 cub. ft.

Power given out by the air: 1·621 cub. ft. × 4504 lbs. per sq. ft. = 7302 ft. lbs.

Useful effect $= \frac{7302 \times 100}{18564} = 39{\cdot}3$ per cent.

Useful effect when the air is used without reheating and without expansion.

Case 5. When the air is used quite cold, without any expansion.

Mean effective pressure = 40 lbs. per sq. in. = 5760 lbs. per sq. ft.

Effective volume 0·95 × 0·9 cub. ft. = 0·855 cub. ft.

Power given out by the air = 0·855 cub. ft. × 5760 lbs. per sq. ft. = 4924·8 ft. lbs.

Useful effect $= \frac{4924{\cdot}8 \times 100}{18564} = 27{\cdot}1$ per cent.

Summary.

SUMMARY.—From the above investigation, it is evident that every source of loss of power, in the application of compressed air, has been taken into account. These sources of loss are:—

1. Loss in raising pressure.
2. Loss by discharge of heat.
3. Loss by friction, leakage, and resistance of valves in air compressing engine.
4. Loss by friction and leakage in mains.
5. Loss by leakage, back pressure, wire drawing and clearance in driven engine.

Notwithstanding all these losses, it will be seen from the five cases given above, that a useful effect remains of from 27 per cent. to 58 per cent., according to the treatment of the air at the consumer's premises.

Explanation of diagram.

The annexed diagrams show the compression, heating and expansion of air. Figure I. gives the compression, that is the work done, at the central station. The formula for adiabatic compression and for isothermal compression are each represented graphically by curves of the respective equations, set out by means of rectangular co-ordinates. The abscissæ are the volumes in terms of the original volume of air at atmospheric pressure; the ordinates are the corresponding pressures in lbs. per square inch. P_m is the mean forward pressure in the compressing cylinder. Figure II. is the diagram of expansion or effective result at the driven engine, according to Case 1 of the calculations; the expansion is taken in terms of the original volume at the driven engine and is measured horizontally; the corresponding pressures are set out vertically. In each diagram the remarks upon it show the relation of work done to effective result obtained.

DIAGRAMS

SHEWING COMPRESSION OF AIR AND EFFECTIVE RESULT.

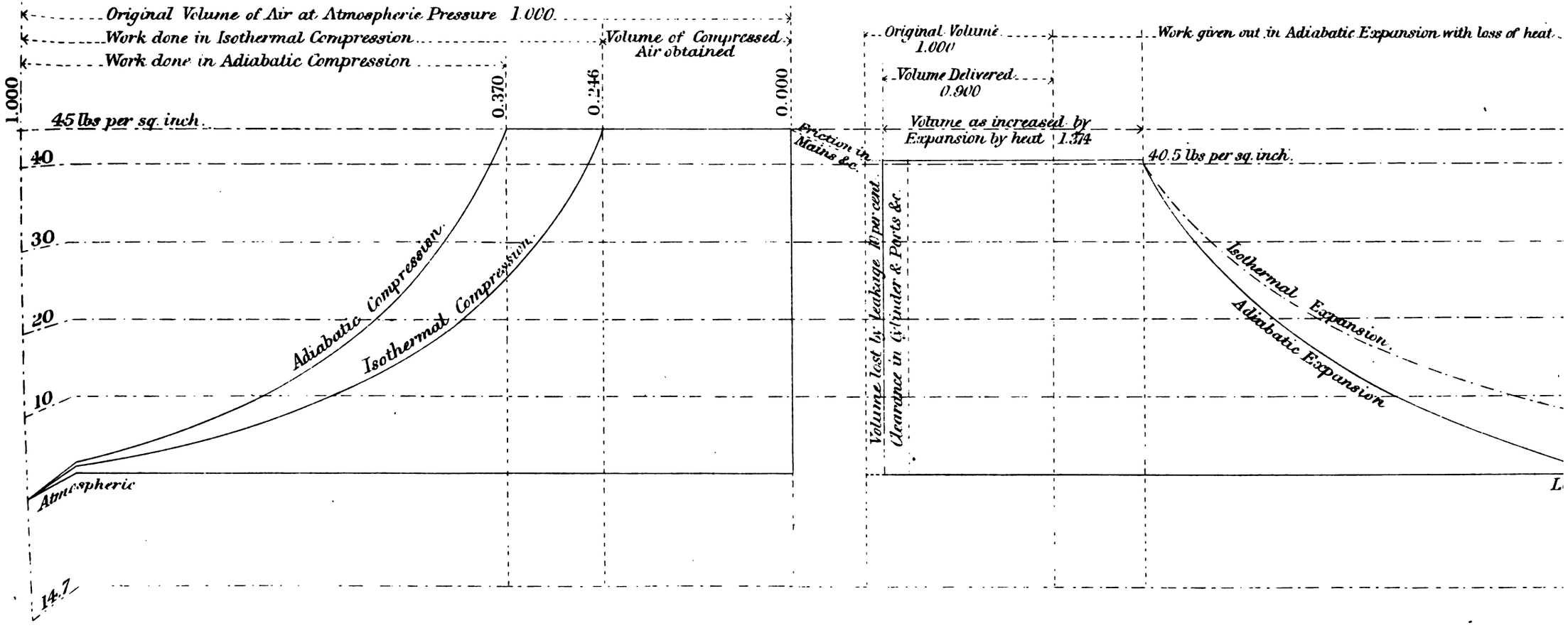
SCALE OF PRESSURES 6 INS.-100 LBS.

FIG 1.

DIAGRAM OF COMPRESSION.

FIG 2.

DIAGRAM OF EXPANSION OR WORK DONE.



The above diagram is constructed from Shone's Tables of Compressed Air. (See Appendix.)

(Resistance of Delivery Valves is included in friction of engine.)

Adiabatic Expansion of Compressed Air heated to 321.3° F.

Mean effective Pressure: "Case 1" in the Calculations - 22.63 lbs per sq. in.

Power Required for Birmingham.—In the wards which at present are to be supplied with compressed air: Deritend, St. Martin's, and St. Bartholomew, the total steam power at present in use is about 10,000 I. H.P. One half of this power we expect will be driven by compressed air, therefore about 5,000 I. H.P., will be required in the district to commence with. Of these, 5,000 I. H.P., the great bulk will be used in the most economical way, and give 58 per cent. of useful effect, but, as a small proportion, especially small engines, will use the air in a less economical way, we assume that the average per centage of useful effect will be 54 per cent. The power required at the air-compressing works will therefore be

Power required for Birmingham.

Indicated H.P. to be supplied in compressed air.

$$54 : 5000 = 100 : 9259 \text{ I. H.P.}$$

or in round numbers about 9300 Indicated Horse Power should be developed at the compressing works. But as a number of engines do not work continually, but at intervals, it is not necessary to have the total power available. but only about 90 per cent. of the above or about 8400 I. H.P.

Gross Ind. H.P. at compressing works.

Quantity of Air required per Min.—It takes as shown above 18,564 ft. lbs. to compress 1 cub. ft. of air to 45 lbs. above atmosphere. For 1 cub. ft, of air per min. it therefore takes $\frac{18564 \text{ ft. lbs.}}{33000} = 0{\cdot}5626$ I. H.P. The number of cub. ft. of air is therefore found by dividing 8400 I. H.P. by 0·5626 = $\frac{8400}{0{\cdot}5626} = 14{,}932$ cub. ft. of compressed air per min.

Volume of air required per minute.

Capacity of the Air Compressing Cylinders.—The quantity of air taken in per minute for compression to 45 lbs. above atmosphere is equal to 4.0612 times the volume of the compressed air = 14932 cub. ft. × 4·0612 = 60643 cub. ft. of air.

Size of air compressing cylinders.

It is proposed to use three sets of air compressors, each with two compressing cylinders, with a piston speed of 720 feet per min.

Piston area of each compressing cylinder is therefore:

60643 cub. ft. ÷ (720 feet piston speed × 6 cylinders).

= 14·038 square ft. = 4·23 ft. diameter = 50¾ ins.

Length of Stroke = 5 ft.

Number of revolutions per min. = $\frac{720 \text{ ft.}}{2 \times 5 \text{ ft.}} = 72$ revolutions per min.

Principal Dimensions of the driving Steam Engines:

Steam cylinders.

Steam pressure in the boilers = 115 lbs. per sq. in. (including atmosphere).

Initial steam pressure in the steam cylinders = 112 lbs. (absolute)

Total expansion (including clearance) = 11·5.

Ratio of H.P. cylinder to L.P. cylinder = 1 to 4·02.

Cut off in H.P. cylinder = 0·42.

Cut off in L.P. cylinder = 0·34.

Average pressure in both cylinders,

$\frac{1 \times \log_e 11{\cdot}5}{11{\cdot}5} \times 112$ lbs. per sq. in. = 0·2993 × 112 lbs. = 33·5 lbs.

Calculation of power.

Loss of pressure by clearance in the cylinders, the steam passages, the receiver &c. = 20 per cent.

Average effective forward pressure 33·5 lbs. × 0·80 = 26·80 lbs. per sq. in.

Back pressure = 4·3 lbs. per sq. in.

Mean effective pressure = 26·8 lbs. − 4·3 lbs. = 22·5 lbs per sq. in.

8,400 I. H.P. to be developed by three pairs of engines, each pair to be $\frac{8400}{3} = 2800$ I. H.P.

If we call the area of the H.P. cylinder x sq. in., then the area of the L.P. cylinder $= 4{\cdot}02\ x$, and the total area of both cylinders $= 5{\cdot}02\ x$.

We have then

$$5{\cdot}02\ x. = \frac{2800 \text{ I. H.P.} \times 33000 \text{ ft. lbs.}}{720 \text{ ft. per min.} \times 22{\cdot}5 \text{ lbs. per sq. in.}} = \frac{92400000}{16200} = 5704 \text{ sq. in.}$$

Principal dimensions of steam cylinders.

Effective area of H.P. cylinder $= \frac{5704}{5{\cdot}02} = 1136{\cdot}2$ sq. in.

Effective area of L.P. cylinder $= 5704 - 1136{\cdot}2 = 4567{\cdot}8$ sq. in.

Diameter of piston rods for both cylinders = 10″ diam. = 78·54 sq. in. below 6″ diameter = 28·27 sq. in. above. Average = 53·40 sq. in.

Total area of H.P. cylinder = 1189·7 sq. in. = say 39″ diameter.

Total area of L.P. cylinder = 4621·2 sq. in. = say 76¼″ diameter.

Length of stroke = 5 ft.

Steam used.

The quantity of steam used per I. H.P. per hour ought not to exceed 16 lbs. (Mair, *The Independent Testing of Steam Engines*, paper read before Institute Civil Engineers, gives for a compound receiver engine with 21″ and 36″ cylinders and 5′ 6″ stroke 14·83 lbs. of steam.) To this must be added 1 lb. of steam per I. H.P. per hour for the auxiliary engines, viz. feed pumps, centrifugal circulating pumps and elevators, making a total of 17 lbs. of steam per I. H.P. per hour. Total quantity of steam required per hour = 3 × 2800 × 17 lbs. = 142800 lbs.

Coal used.

Quantity of coal to be used. As coal "slack" is to be used we cannot, even with mechanical stokers, on account of the high pressure of the steam, expect a higher evaporation than 8·5 lbs. of water per 1 lb. of coal.

Quantity of coal to be used per hour $= \frac{142800}{8{\cdot}5} = 16800$ lbs. of coal.

Coal used per I. H.P. per hour $= \frac{17 \text{ lbs.}}{8{\cdot}5} = 2$ lbs. of coal.

Boilers.

Steam Boilers. Total grate area necessary for burning 16800 lbs. of coal per hour. 15 lbs. of coal can be burned per sq. ft. of grate per hour, with good results.

$$\text{Total grate area} = \frac{16800}{15} = 1120 \text{ sq. ft.}$$

It is found most suitable to distribute this grate area on 40 boilers arranged in four rows, so that in each row 10 boilers are in use and 1 boiler extra is added for reserve, so that the total number of boilers is 44.

Grate area in each boiler $= \frac{1120}{40} = 28$ sq. ft. = 5′ broad and 5′ 8″ long.

Heating surface required for each boiler = 30 × 28 sq. ft. = 840 sq. ft.

Heating surface of boiler 7′ 6″ diam. with two internal flues each 3′ 0″ diam. per lineal foot of boiler.

Boiler shell exposed to direct heat = 13·3 ft. × 1 ft. -	= 13·30 sq. ft.
2 internal flues, 3 ft. diam. = 2 × 3·1416 × 3 ft. × 1 ft.	= 18·85 sq. ft.
Galloway tubes, 10″ to 6″ diam.. 3 feet long each, with 5·96 sq. ft. surface in each flue, with an average distance of 3′ 5¼″ apart. Surface pr. lin. ft. of boiler $= \frac{2 \times 5{\cdot}96}{3{\cdot}43}$ = - - - - - - - -	3·43 sq. ft.
Heating surface pr. lin. foot of boiler -	35·58 sq. ft.

Length of boiler required $= \frac{840 \text{ sq. ft.}}{35{\cdot}58 \text{ sq. ft.}} = 23{\cdot}6$, say 24 feet long with 7 Galloway tubes in each flue.

Brickwork Boiler Setting, with one flue in front and one flue at the back of the boiler, each 14″ wide; with front wall and back wall each 18″ thick, and 2″ clearance space between boiler-setting and boiler-house wall - - - - - - - - - - - - - 5′ 6″ Boiler setting and flues.

Length of boiler shell - - - - - - -	24′	0″
Length of boiler-setting over all - -	29′	6″

Breadth of Boiler Setting—

Diam. of boiler shell - - - - - - - -	7′	6″
Width of two flues - - - - - - - -	3′	3″
Thickness of one side wall - - - - - - -	1′	6″
Total breadth - -	12′	3″

Chimney for a consumption of 16800 *lbs. of Coal per hour*—

Height of chimney = 150 feet.

Area of chimney at the top $= \frac{15 \times 16800 \text{ lbs.}}{\sqrt{150 \text{ ft.}}} = \frac{252000}{12{\cdot}247} = 20576$ sq. in. $= \frac{20576}{144} =$ 142·8 sq. ft. = 13′ 6″ diam. Chimney.

Outside diam. at the top = 13′ 6″ + 2 × 13½″ = 15′ 9″ diam.

Batter of chimney = 1 : 40 $= \frac{150 \text{ ft.}}{40} = 3'\ 9''$ on each side.

Outside diam. at the ground = 15′ 9″ + (2 × 3′ 9″) = 23′ 3″ diam.

Thickness of brickwork in chimney. 50 feet from the top 1½ brick, and increasing ½ brick for every 25 ft. length, $\frac{150-50}{25} = 4$ lengths thickness of brickwork at ground line = 1½ brick + (4 × ½) brick = 3½ bricks = 2′ 7½″ thick.

Inside diam. at ground line = 23′ 3″ − (2 × 2′ 7½″) = 18′ 0″ diam.

Dimensions of Main Flue—

Each 1 lb. of coal requires about 275 cub. ft. of air, at atmospheric pressure, and 60° F. temperature, for its combustion in an ordinary furnace. The temperature in the main flue will be about 500° F., and the volume of the products of combustion will therefore be: Main flue.

Atmospheric air - - - - - - -	275 cub. ft.
1 lb. of coal $\frac{84 \text{ cub. ft}}{2}$ - - - - - -	17 cub. ft.
	292 cub. ft.

This volume of air heated from 521° F. absolute to 961° F. absolute, becomes

$$292 \text{ cub. ft.} \times \frac{961 - 28°}{521 - 28°} = 292 \times \frac{933°}{493°} = 553 \text{ cub. ft. of gases.}$$

The total volume of hot gases to be discharged per hour through the main flue is, therefore,

16800 lbs. of coal × 553 cub. ft. = 9290400 cub. ft. per hour.
= 2581 cub. ft. per second.

The theoretical velocity of air in the chimney is found from the following formula:

$$V = \sqrt{\frac{2 \times g \times H \times a\,(T - t)}{1 + a\,T}}$$

where

V = velocity.

g = the velocity due to gravity = 32·2 ft. per sec.

H = height of chimney = 150 ft.

T = temperature of the hot gases = 500°

t = temperature of the outside air = 60°

a = co-efficient of expansion for air = 0·00203.

$$V = \sqrt{\frac{2 \times 32{\cdot}2 \times 150 \times 0{\cdot}00203 \times 440°}{1 + (0{\cdot}00203 \times 500)}} = \sqrt{4282} = 65{\cdot}4 \text{ ft. per sec.}$$

The real velocity in the flues is, however, only 30 per cent. of the above

$= 65{\cdot}4 \times {\cdot}30 = 19{\cdot}62$ ft. p. sec.

Size of flue.

Area of flue $= \frac{2581}{19{\cdot}62} = 132$ sq. ft. $= 6$ ft. deep $\times$ 22 ft. wide.

Reheating the Compressed Air at the Driven Engines.

Reheating the air.

For motive power purposes, to utilize compressed air with the best economical result, it is necessary to re-heat it before it enters the cylinder of the engine to be driven. Not only is the loss great by allowing air compressed to 45 lbs. above atmosphere and at 60° F. to expand to atmospheric pressure as shown by Case 3, page 27, where the total loss is about 62 per cent., but the temperature of the air sinks during the expansion down to −114° F. (= − 81° C.), a temperature at which the cylinder, the piston rod, exhaust pipe, &c., would be covered with ice, the natural moisture of the atmosphere condensing and forming ice on the cold surfaces, which would in a great measure prevent the use of compressed air except for engines working without expansion.

Effect of using the air without reheating.

Temperature required to avoid inconvenience from freezing, &c.

Fortunately, however, the compressed air needs only to be heated to 321° F. (= 161° C.) to avoid all these evils and to ensure its economical application. Even the best of fire-places send off the products of combustion at this temperature as waste heat, and it is only necessary to let the supply or service pipe go through the nearest flue and expose sufficient surface to the hot gases, to obtain a very considerable increase in power at very little cost.

Weight of a cub. ft. of air at ordinary pressure = 0·08072 lbs.

Do. do. do. at 45 lbs. above atmosphere $= \frac{0{\cdot}08072}{0{\cdot}246} = 0{\cdot}3281$ lbs.

Specific heat of air at constant pressure = 0·23751.

Heat required per cubic foot.

Heat required to raise 1 cub. ft of air from 60° to 321° F = 261° × 0·3281 lbs. × 0·23751 = 20·339 thermal units, and as air expands $\frac{1}{490}$rd of its volume for each degree F. it is heated, it becomes $1 + \frac{261°}{490} = 1{\cdot}53$ cub. ft. of hot air.

Power represented thereby.

The mechanical equivalent of one thermal unit is, according to Joule, = 772 foot lbs. per second. If, therefore, 1 cub. ft. of air be heated from 60° to 321° F. in one second it takes up $20{\cdot}339 \times 772$ ft. lbs.

which can be given out as useful work in expansion as shown in Case 1, page 26.

It is a fundamental principle that compressed air cannot give out power without losing heat, and the lost heat is exactly in proportion to the work done. If, therefore, the air compressed to 45 lbs. and heated to 321° F. be expanded 4·06 times, it is given out at normal pressure and normal temperature after having done work equal to the heat given out.

Reheating surface required per Ind. H.P.

Surface required to re-heat air per horse-power. As one cub. ft. of cold air per second (measured at the air compressing works), re-heated, gives out 10,819 ft. lbs., as shown in Case 1, page 26, or about 19·6 H.P. per second, it is evident that one horse-power uses $\frac{1}{19·6}$ cub. ft. per sec., or $\frac{3600}{19·6} = 183$ cub. ft. of cold air per hour. The average temperature of the air is $\frac{321+60}{2} = 190·5°$ F., and the temperature in flues usually about 600°F. If now the air be enclosed in wrought iron tubes, $\frac{1}{4}''$ thick, the flow of heat per sq. ft. per hour through these tubes will, according to the experience gained with air-heating apparatus for houses and buildings, be 1·23 thermal units per sq. ft. per hour for 1° F. difference of temperature.

Therefore the quantity of air at the consumer's premises being 0·9 × 183 = 165 cub. ft., the heat required per hour is 165 cub. ft. × 20·339 = 3356 thermal units.

The average difference of temperature is 600 − 190·5 = 409·5° F.

The amount of heat transmitted per sq. ft. = 409·5 × 1·23 = 503·7 thermal units.

Area of heating surface.

The area of heating surface required for each horse-power is therefore $= \frac{3356}{503·7} = 6·66$ square ft.

The velocity of the air through the heating apparatus should not exceed 1 ft. per second = 3600 ft. per hour. Area of pipe $= \frac{165 \times 144}{3600}$ = 6·6 sq. in. = 3″ dia., the internal circumference of which is 9·42″:— therefore, the length required $\frac{12 \times 6·66}{9·42} = 8$ ft. 6 ins.

When waste heat is intermittent.

In case the available waste heat is intermittent instead of being constant, the same result can be obtained by surrounding the tube to be heated with some substance which fuses at the temperature of the flue, binding a great quantity of heat in liquifying, and giving it out again in cooling, as for instance potassium acetate of which the freezing point is 600° F.

When the temperature is higher than required.

In case the temperature of the flue is very much higher than required, such for instance as the flues of puddling and smelting furnaces, the tube to be heated should be protected by fireproof brickwork, which retains the heat and equalises the temperature.

ESTIMATE

FOR

THE BIRMINGHAM AIR COMPRESSING WORKS.

No.	Quantity.	Description of Work.	Cost of Work. £ s. d.	£ s. d.
		I.—BUILDING WORK.		
		(*a*)—ENGINE-HOUSE.		
1	4184	Cubic yards of earth to excavate for the foundations of the house and the Engines. The excavated earth partly to be rammed firmly around the finished foundations, partly to to be removed from the premises, at 2*s.* 6*d.*	523 0 0	
2	470	Cubic Yards of Concrete (consisting of 1 part of Portland Cement, 4 parts of sharp clean sand and 8 parts of angular stones, carefully mixed and firmly rammed into the mould) as foundations under the side and end walls of the building, at 16*s.*	376 0 0	
3	3116	Cubic yards of Brick-work for side and end walls of Engine-house, of thoroughly good and well-burnt bricks in mortar (1 of lime and 3 of sharp sand) at £1 6*s.*	4,050 16 0	
4	1385	Cubic yards of Concrete (1 of Portland cement, 3 of sharp clean sand and 6 of angular stones) for foundations for 4 sets of Air compressors, Carefully finished, at £1	1,385 0 0	
5	2700	Square yards; outside surface of Engine-house to be faced with extra		
		Carried forward	6,334 16 0	

No.	Quantity.	Description of Work.	Cost of Work. £	s.	d.	£	s.	d.
		Brought forward	6,334	16	0			
		good, well-formed, well-burnt, non-porous, hard red bricks, with specially shaped bricks for cornices, plinths, door and window openings, &c., and with different coloured bands of grey glazed bricks as an addition to No. 3. Complete at 5*s*.	675	0	0			
6	2100	Square yards of plastering on inside walls of Engine-house (1 of lime and 2 of sharp river sand) carefully finished and painted three times with oil paint, at 2*s*. 4*d*.	245	0	0			
7	665	Square yards of rubbed Yorkshire flags laid on Concrete (1 of Portland cement, 4 of sand, 8 of angular stones) for Engine-house floor, at 15*s*.	498	15	0			
8	33	Tons of wrought iron work for the roof, carefully fitted, fixed, erected and painted, at £30	990	0	0			
9	135	Squares of 1 in. boarding, planed on one side, grooved and feathered, and fixed to the principals, oiled three times with boiled linseed oil, per 100 square feet, at £2 8*s*.	324	0	0			
10	144	Squares of best slating laid on boards and end walls, complete, at £2 6*s*. 6*d*.	334	16	0			
11	90.4	Lineal yards of eave gutter, at 3*s*.	13	11	3			
12	146	Lineal yards of clay-socket pipes 6 in. diameter, built in the walls of the Engine-house to drain the eave gutters, at 4*s*.	29	4	0			
		Carried forward	9,445	2	3			

No.	Quantity.	Description of Work.	Cost of Work.					
			£	*s.*	*d.*	£	*s.*	*d.*
		Brought forward	9,445	2	3			
13	84	Wrought iron arched windows, 10 ft. high and 6 ft. broad, glazed with best white window glass, fixed and painted, at £7.	588	0	0			
14	2	Wrought iron circular windows, 10 ft. diameter, glazed &c., as above	14	0	0			
15	2	Arched doorways, 15 feet high, 10 ft. broad, in strong frames, strong hinges, locks and bolts, fixed and painted, at £40	80	0	0			
16	1	Door to fitting and turning shop 8 ft. high, 4 ft. broad in strong frame with hinges, lock and bolts, fixed and complete	6	0	0			
17	14	Squares of skirting, 3 ft. 6 in. high, along the Engine-house walls, of ¾ in. edge feathered boards, planed on one side, fixed and oiled three times with boiled linseed oil at £2 10*s*	35	0	0			
18	....	Door steps, window sills and various other fittings	200	0	0			
						10,368	2	3
		(*b*)—Two Boiler Houses and Coal Stores.						
1	6027	Cubic yards of earth to excavate for the foundations of Boiler-house walls and Boilers for the floors and underground flues. The excavated earth partly to be rammed firmly around the finished brick-work, partly to be removed from the premises, at 2*s.* 6*d.*	753	7	6			
		Carried forward	753	7	6	10,368	2	3

No.	Quantity.	Description of Work.	Cost of Work.					
			£	*s.*	*d.*	£	*s.*	*d.*
		Brought forward	753	7	6	10,368	2	3
2	1260	Cubic yards of concrete (1 of Portland Cement, 4 of sharp clean sand, 8 of angular stones) as foundations under the side, middle and end walls, and Boilers, at 16*s.*	1,008	0	0			
3	3902	Cubic yards of Brick-work for side, middle and end walls of Boiler-houses and coal-stores, of thoroughly good and well-burnt bricks in mortar at £1 6*s.*	5,072	12	0			
3A	728	Cubic yards of Brick in Portland cement, for underground flues, at £1 11*s.*	1,128	8	0			
4	3056	Cubic yards of Brickwork boilers setting of well-burnt bricks in clay, at £1 4*s.*	3,667	4	0			
4A	2160	Square yards internal surface of boiler-flues, to be lined with fire bricks, carefully set in fire clay, as addition to No. 4, at 8*s.*	864	0	0			
5	3347	Square yards outside surface of boiler-house, coal stores and boilers, to be faced with extra good bricks, and finished in the same way as the Engine house, at 5s.	836	15	0			
6	4860	Square yards of plastering on the inside walls of Boiler-house and coal stores, lime washed and coloured, at 1*s.* 4*d.*.....	324	0	0			
7	1045	Square yards of Iron-bricks, laid on concrete for Boiler-house and coal stores floor, at 12*s.*.....	627	0	0			
		Carried forward	14,281	6	6	10,368	2	3

No.	Quantity.	Description of Work.	Cost of Work.					
			£	s.	d.	£	s.	d.
		Brought carried	14,281	6	6	10,368	2	
8	70	Tons of wrought-iron work for the 2 roofs, with ventilators, carefully fitted, fixed, erected and painted, at £30	2,100	0	0			
9	287·4	Squares of 1 in. boarding, planed on one side, grooved and feathered, fixed to the principals, and oiled three times with boiled linseed oil, at £2 8*s*.	689	15	3			
10	296·4	Squares of slating, laid on boards, at £2 6*s*. 6*d*.	689	2	7			
10A	4500	Square feet of glass panes laid on rods of zinc and iron for skylight on boiler-houses and coal stores, at 2*s*.	450	0	0			
11	224	Lineal Yards of eave gutters, at 3*s*.	33	12	0			
12	66	Lineal yards of Clay socket-pipe 7 in. diameter, built into the walls of the boiler-house and coal stores, to drain the eave gutters	16	10	0			
13	4	Circular wrought iron windows 10 ft. diameter, glazed, fixed and painted, at £7	28	0	0			
14	46	Lineal yards of light railway viaduct, on cast iron columns, with wrought iron superstructure 13 ft. 6 in. high, 9 ft. broad, with light rails, 2 ft. gauge, at per lineal yard, £12 10*s*. .	575	0	0			
14A	800	Lineal yards of light railway, 2 ft. gauge, at 8*s*.	320	0	0			
		Carried forward	19,183	6	4	10,368	2	3

No.	Quantity.	Description of Work.	Cost of Work.					
			£	s.	d.	£	s.	d.
		Brought forward	19,183	6	4	10,368	2	3
14B	2	Rotating bucket elevators to lift coal, 18 ft. high from the coal barges to the Railway, trucks, with engines, cranes, &c., complete	1,400	0	0			
14C	8	Improved Tip Wagons, each 2 ft. 8 in. deep by 2 ft. broad and 4 ft. long, to carry 1,000 lbs. of coals, £15	120	0	0			
15	8	Arched doorways, 8 ft. high by 5 ft. broad in strong frames, with all fittings, fixed and painted, at £6....	48	0	0			
16	1	Entrance door to Boiler-house, 7 ft. high by 3 ft. wide, with all fittings fixed and painted	4	0	0			
17	147	Cubic ft., 12 in. by 8 in. beams for upper floor in boiler-house entrance, at 4*s* 6*d*.	33	1	6			
17A	8	Squares of oak floor in ditto at £3 5*s*. 0*d*.	26	0	0			
						20,814	7	10
		(*c*)—Chimney for Steam Boilers.						
1	590	Cubic yards of earth to excavate for the foundations (10 ft. deep). The earth partly to be rammed firmly around the finished foundations, partly to be removed from the premises, at 5*s*.	147	10	0			
2	79	Cubic yards of Concrete (1 of Portland cement, 3 of sharp clean sand, 6 of angular stones) as foundations under the Chimney, at 18*s*.	71	2	0			
3	660	Cubic yards of Brickwork for Chimney shaft, foundations of thoroughly good and well-burnt bricks in mortar, at £2	1,320	0	0			
		Carried forward	1,538	12	0	31,182	10	1

No.	Quantity.	Description of Work.	Cost of Work. £ s. d.	£ s.
		Brought forward	1,538 12 0	31,182 10
4	1085	Square yards outside surface of Chimney to be faced with extra good bricks, finished in the same way as the engine-house, at 6*s*.	325 10 0	
5	890	Square yards of inside walls of Chimney to be rendered and set, at 1*s*. 6*d*.	66 15 0	
6	3	Tons of cast iron plates to cover the top of the Chimney, at £10	30 0 0	
7	1	Lightning Conductor with 160 ft. of ½ in. copper conducting line, insulators, ground plate, &c., fixed complete	30 0 0	
				1,990 17
		(*d*)—PURIFIER FOR UNCOMPRESSED AIR.		
1	186	Cubic yards of earth to excavate for the foundations (5 ft deep). The earth to be partly rammed firmly around the finished foundations, partly to be removed from the premises. at 2*s*. 6*d*.	23 5 0	
2	24·8	Cubic yards of Concrete floor, 9 in. thick (1 of Portland Cement, 3 of sharp clean sand, 6 of angular stones) at £1.	24 16 0	
3	692	Cubic yards of Brick-work in Portland cement (1 cement, 3 of sand) for foundations, side walls, cupola, brick arches, &c., of thoroughly, good and well-burnt bricks, at £1 11*s*.	1,072 12 0	
		Carried forward	1,120 13 0	33,173 7

No.	Quantity.	Description of Work.	Cost of Work.					
			£	s.	d.	£	s.	d.
		Brought forward	1,120	13	0	33,173	7	1
4	1003	Square yards outside surface of Purifier, to be faced with extra good bricks, and finished in the same way as the engine-house, at 5s.	250	15	0			
5	1663	Square yards of Portland cement plastering on all the inside surfaces of the Purifier, and on the outside surfaces of the Cupola and the brick arches, at 3s.....	249	9	0			
6	1	Apparatus for letting sprays of clean water fall through the air, sucked in by the Compressors	150	0	0			
7	2	Canvas screens, 20 ft. high, 15 ft. wide in strong wooden frames, with rollers above and below running on light rails	300	0	0			
8	1.2	Tons of wrought iron for 160 steps and two iron girders, protected from rust by the Bower-Barff patent. The steps to be let into the wall of the air shaft inside and outside, and the wrought iron girders to carry the partition walls to the filtering space, at £15	18	0	0			
9	226	Cubic feet of timbering for scaffolding outside the Purifiers for cleaning and drying the Canvas screens, at 6s.	67	16	0			
						2,156	13	
		(*e*)—Office Buildings.						
1	130	Cubic yards of earth to excavate for the foundations of the outside, and partition walls, the excavated earth						
		Carried forward				35,330	0	1

No.	Quantity.	Description of Work.	Cost of Work.					
			£	*s.*	*d.*	£	*s.*	*d.*
		Brought forward				35,330	0	1
		partly to be rammed firmly around the brick-work, and partly removed from the premises, at 2*s.* 6*d.*	16	5	0			
2	192	Cubic yards of Brick-work for outside and partition walls, of thoroughly good and well-burnt bricks in mortar, at £1 6*s.*	249	12	0			
3	537	Square yards of outside surface of office buildings to be faced with extra good bricks in the same way as the engine-house, at 5*s.*	134	5	0			
4	1056	Square yards of plastering on the inside walls of the office buildings carefully finished and painted three times with oil paint, at 2*s.* 4*d.*	123	4	0			
4A	267	Square yards of plastering for ceiling, carefully finished, at 2*s.*	26	14	0			
5	570	Cubic feet of 2½ in. deals for ground floor, wall plates, first floor and roofs, fixed and erected, at 6*s.*	171	0	0			
6	62	Squares of 1 in. boarding for roof, two floors and two ceilings at £2 8*s.*	148	16	0			
7	1400	Square feet of zinc plates to cover the roof, at 9*d.*	52	10	0			
8	1	Staircase with 15 steps, wooden hand rail, &c., height of step 8 in., breadth 12 in. Total height of staircase 10 ft.	15	0	0			
9	3	Outside doors 2 ft. 8 in. wide, 7 ft. high with strong hinges, locks and chains, in strong frames complete fixed and painted, at £5	15	0	0			
		Carried forward	952	6	0	35,330	0	1

No.	Quantity.	Description of Work.	Cost of Work.					
			£	*s.*	*d.*	£	*s.*	*d.*
		Brought forward	952	6	0	35,330	0	1
10	10	Inside doors 2 ft. 8 in. wide 7 ft. high with strong hinges, locks and chains in strong frames, complete fixed and painted, at £4	40	0	0			
11	25	Windows 3 ft. wide, 6 ft. high, glazed with best white glass, the sashes to be well balanced and the frames fitted with Venetian blinds, at £5.	125	0	0			
12	....	Internal fittings, viz., 8 chimneys, 1 w.c., tables, chairs, desks, 6 wash-stands and various office fittings, &c.	500	0	0			
13	6	Lineal yards Sandstone steps 6 in. high, 12 in. wide, outside the entrance door, at 6*s.*	1	16	0			
14	29	Lineal yards of eave gutter, at 2*s.*	2	18	0			
15	28	Lineal yards of rain pipe, at 2*s.* 6*d.*.....	3	10	0			
						1,625	10	0
		(*f*)—Turning and Fitting Shop.						
1	150	Cubic yards of earth to excavate for the foundations of the shop, and of the tool machinery. The excavated earth partly to be rammed firmly around the finished foundations, partly to be removed from the premises, at 2*s.* 6*d.*	18	15	0			
2	105	Cubic yards of Brick-work for foundations, and side walls of the shop of thoroughly good and well-burnt bricks in mortar, at £1 6s.	136	10	0			
		Carried forward	155	5	0	36,955	10	1

No.	Quantity.	Description of Work.	Cost of Work.					
			£	s.	d	£	s.	d.
		Brought forward	155	5	0	36,955	10	1
3	85	Cubic yards of concrete (1 of Portland cement, 3 of sand, and 6 of angular stones) for foundations for various tools complete, at 18*s*.	76	10	0			
4	201	Square yards outside surface of Fitting and Turning shop to be faced with extra good bricks, and finished in the same way as the engine-house, at 5*s*.	50	5	0			
5	184	Square yards of plastering on the inside walls of fitting and turning shop, lime washed and coloured, at 1*s*. 4*d*.	12	5	4			
6	56	Square yards of floor in the shop, consisting of wood pavement, laid on concrete, at 8*s*.	22	8	0			
7	2	Tons of wrought iron work for the roof, carefully fitted, erected and painted, at £30	60	0	0			
8	7.95	Squares of 1 in. boarding, planed on one side, grooved and feathered, fixed to the principals, and oiled 3 times with boiled linseed oil, at £2 8*s*.	19	1	8			
9	8.30	Squares of slating, laid on boards, at £2 6*s*. 6*d*.	19	5	11			
10	22	Lineal yards of eave gutter, at 2*s*.	2	4	0			
11	10	Lineal yards of vertical rain pipe, 4 in. diameter, at 2*s*. 6*d*.	1	5	0			
		Carried forward	418	9	11	36,955	10	1

No.	Quantity.	Description of Work.	Cost of Work.					
			£	*s.*	*d.*	£	*s.*	*d.*
		Brought forward	418	9	11	36,955	10	1
12	8	Wrought iron, arched windows, 4 ft. wide, 7 ft. high, glazed, fixed and painted, at £2 16*s.*....	22	8	0			
13	1	Arched doorway with overlight, 4 ft. wide, 9 ft. high, in strong frame, with lock, bolts and hinges, painted and fixed....	7	0	0			
14	....	4 lathes, 1 planing machine, 1 slotting and 1 drilling machine, 1 vice bench, with 4 vices, files, hammers, gas tongs, 1 grindstone, small steam engine, 30 ft. of shafting, &c., &c.	1,100	0	0			
						1,547	17	11
		(*g*)—Smith Shop.						
1	36	Cubic yards of earth to excavate for the foundations, the earth partly to be rammed firmly around the finished Brick-work, partly to be removed from the premises, at 2*s.* 6*d.*	4	10	0			
2	58	Cubic yards of Brick-work for the foundations, side and end walls, and for 2 smith's fireplaces, of thoroughly good and well-burnt bricks in mortar, at £1 6*s.*	75	8	0			
	120	Square yards of outside surface of Smith's shop to be faced with extra good bricks, in the same way as the engine-house, at 5*s.*	30	0	0			
	92	Square yards of inside walls of Smith's shop to be rendered and set, at 1*s.* 4*d.*	6	2	8			
		Carried forward	116	0	8	38,503	8	0

No.	Quantity.	Description of Work.	Cost of Work.					
			£	s.	d.	£	s.	d.
		Brought forward	116	0	8	38,503	8	0
5	17	Square yards of granite pavement in Smith's shop, at 10*s.*	8	10	0			
6	0.5	Ton of wrought iron work for the roof, carefully fitted, fixed, erected and painted, at £30	15	0	0			
7	3.52	Squares of slating laid on angle irons, at £2 8*s.*	8	9	0			
8	22	Lineal yards of eave gutter, at 2*s.*	2	4	0			
9	10	Lineal yards of 4 in. vertical rain pipe, at 2*s.* 6*d.*	1	5	0			
10	4	Arched wrought iron windows 3 ft. wide, 6 ft. high, glazed, fixed and painted, at £2 10*s.*....	10	0	0			
11	1	Plain entrance door, 3 ft. wide, 7 ft. high, fixed and painted	3	0	0			
12	2	Sets of Smith's tools, hearths, small power hammer, anvils, hammer, tongs, chisels, &c., &c.	200	0	0			
						364	8	8
		II.—AIR COMPRESSING MACHINERY.						
		BOILERS.						
1	44	Steam Boilers of the best B. B. Staffordshire iron with furnaces of Lowmoor iron. Each boiler to be 7 ft. 6 in., diameter 29 ft. 6 in., long with 2 internal corrugated Fox flues of 3 ft. diameter, each flue fitted with 8 Galloway tubes. Each						
		Carried forward				38,867	16	8

No.	Quantity.	Description of Work.	Cost of Work.					
			£	s.	d.	£	s.	d.
		Brought forward				38,867	16	8
		boiler to be fitted with all the usual cocks, valves and other fittings, with manhole, steam dome, safety valve, &c. And also with Juckes' revolving fire bars, and with an iron hopper 12 ft. 6 in. long, 5 ft. broad, to hold 1500 lbs. of small coal, and to be fixed to the boiler house and railway viaduct in such a way that the coal trucks may be tipped direct into the hopper. The grate surface to be 5 ft. broad by 5 ft. 9 in. long. The boilers to stand a working pressure of 100 lbs. per square inch above atmosphere. Thickness of boiler-plates $\frac{7}{16}$ in. Total weight of boiler with hopper, 18.5 tons. Price per boiler, £650	28,600	0	0			
		AIR COMPRESSORS WITH ENGINES.						
2	4	Complete sets of Trunk Air Compressors, with vertical compound, Condensing Engines of the Marine Engine type, with Injection condenser. The Air Compressors for each set of Engines to consist of two double acting Trunk Cylinders, each to be 50¾ in. diameter (14 sq. ft. area) with 5 ft. stroke. Each pair of Engines is to indicate 2800 horse-power. The high pressure Cylinder to be 39 in. diameter, the low pressure Cylinder to be 76¾ in. diameter. Steam pressure, 100 lbs. per square inch above atm. Cut						
		Carried forward	28,600	0	0	38,867	16	8

No.	Quantity.	Description of Work.	Cost of Work. £	s.	d.	£	s.	d.
		Brought forward	28,600	0	0	38,867	16	8
		off in high pressure Cylinder, at 0.42 stroke. Cut off in low pressure Cylinder, 0.34 stroke. Ratio of Cylinders 1 : 4.02. Length of Stroke for both Cylinders 5 ft. Piston speed per minute 720 ft. Number of revolutions per minute 72. The Steam Cylinders to be jacketted and filled with live steam from the boilers. The area of Steam ports for the high pressure Cylinder to be 92 sq. in. The area of Steam ports for low pressure cylinder to be 343 sq. in., and all the steam ports to present as small a surface to the steam as possible. The steam cylinder covers to be hollow, and, as well as the steam jacket, to be filled with live steam from the boilers. The steam cylinders to be fitted with spring safety valves, above and below, with auxiliary slide valve, &c., &c. The engine to be fitted with starting gear. The Crank shaft to be of steel, 14 in. diameter, with two slotted cranks at right angles to each other, crank pins to be 18 in. diameter, 22 in. long, the connecting rod from one air cylinder to work on the same crank pin. Main bearings to be 24 in. long, of best Phosphor Bronze. Piston rods to be of steel, 6 in. diameter, with an elongation through top of cylinder 4 in. diameter. Main steam pipe to be 24 in. diameter, decreasing to 12 in. diameter, according to drawing. All parts of steam pipe, valves, cylinders, valve chests, receivers, cylinder cover, and steam						
		Carried forward	28,600	0	0	38,867	16	8

No.	Quantity.	Description of Work.	Cost of Work.					
			£	*s.*	*d.*	£	*s.*	*d.*
		Brought forward	28,600	0	0	38,867	16	8
		jackets to be carefully lagged and drained. All parts of the engines to be easily accessible by stairs and platforms. The degree of expansion and speed of the engine to be regulated automatically by the air pressure in the mains. The air pumps to be 4 ft. 6 in. in diameter, single acting with 12 in. stroke, and to be driven from the cross head of the low pressure cylinder by means of a rocking bar and links. Engines and air compressors to be mounted on a strong substantial well-stayed cast-iron bed-plate, fixed with strong foundation bolts to the concrete foundation, in such a way that no vibrations are caused by the high speed of the engines. All steam and air tight joints are to be metallic, and to keep tight without any packing whatsoever. Price of an engine with air compressor complete, erected and started with all necessary pipes and fittings £10,000	40,000	0	0			
3	2	Centrifugal pumps with engines each to lift about 6000 gallons of water per minute, about 15 ft. high for cooling the air compressing cylinders and for injection water to the condensers. The whole quantity of water to be delivered into the air cylinder water tanks, and from thence to flow into the condensers. Main pipe 18 in. diameter. Price per pump, with pipes, valves and fittings £450	900	0	0			
		Carried forward	69,500	0	0	38,867	16	8

No.	Quantity.	Description of Work.	Cost of Work. £ s. d.	£ s. d.
		Brought forward	69,500 0 0	38,837 16 8
4	2	Donkey pumps with engines to supply the boilers. Each pump to give 250 gallons of water per minute, with a piston speed not exceeding 100 ft. per minute. Price per pump with all pipes, valves and fittings, £300	600 0 0	
5	1	20 ton portable wrought iron A shaped crane with 25 ft. span, 36 ft. high to move on two line of rails; complete with crab, driving gear, rails, &c.	750 0 0	
				70,850 0 0
		III.—CAST IRON-MAINS.		
1	244	Lineal yards of 30 in. socket-pipe laid and joined, including excavation, filling up, paving, &c., per yard, £3 10*s*. 6d.	860 2 0	
	44	Lineal yards 24 in. do. £2 8*s*. 8*d*.	107 1 4	
	3570	Do. 20 in. do. £1 18*s*. 4*d*.	6,842 10 0	
	1590	Do. 18 in. do. £1 11*s*. 0*d*.	2,464 10 0	
	2360	Do. 16 in. do. £1 6*s*. 8*d*.	3,146 13 4	
	2860	Do. 14 in. do. £1 2*s*. 4*d*.	3,193 13 4	
	7470	Do. 12 in. do. £0 18*s*. 6*d*.	6,909 15 0	
	7690	Do. 10 in. do. £0 14*s*. 10*d*.	5,703 8 4	
	1470	Do. 9 in. do. £0 14*s*. 0*d*.	1,029 0 0	
	4780	Do. 8 in. do. £0 11*s*. 9*d*.	2,808 5 0	
		Carried forward	33,064 18 4	109,717 16 8

No.	Quantity.	Description of Work.	Cost of Work.					
			£	*s.*	*d.*	£	*s.*	*d.*
		Brought forward	33,064	18	4	109,717	16	8
	1120	Lineal yards of 7 in. socket-pipe laid and joined, including excavation filling up, paving, &c. 10*s.* 8*d.*	597	6	8			
	9770	Do. 6 in. do. £0 9*s.* 0*d.*	4,396	10	0			
	2330	Do. 5 in. do. £0 7*s.* 9*d.*	902	17	6			
	780	Do. 4 in. do. £0 6*s.* 7*d.*	256	15	0			
2	220	Tons of bends and connections, laid and joined, but exclusive of earthwork and paving, per ton £12 10*s*....	2,750	0	0			
3	33	Sluice-valves for 20 in. pipe with street boxes complete, laid and joined, at £28 8*s.* 6*d.*	938	0	6			
	7	18 in. do. .... £25 12*s.* 0*d.*	179	4	0			
	12	16 in. do. .... £22 1*s.* 4*d.*	264	16	0			
	15	14 in. do. .... £16 18*s.* 8*d.*	254	0	0			
	36	12 in. do. .... £13 4*s.* 0*d.*	475	4	0			
	39	10 in. do. .... £10 18*s.* 4*d.*	425	15	0			
	8	9 in. do. .... £9 12*s.* 0*d.*	76	16	0			
	24	8 in. do. .... £8 6*s.* 8*d.*	200	0	0			
	6	7 in. do. .... £7 2*s.* 4*d.*	42	14	0			
	49	6 in. do. .... £6 1*s.* 6*d.*	297	13	6			
	12	5 in. do. .... £5 3*s.* 8*d.*	62	4	0			
	5	4 in. do. .... £4 7*s.* 2*d.*	21	15	10			
4	230	Self acting Syphons, at £3 0*s.* 0d.	690	0	0			
						45,896	10	4
		Carried forward				155,614	7	0

No. Quantity.	Description of Work.	Cost of Work. £ s. d.	£ s. d.
	Brought forward		155,614 7 0
	IV.—SERVICE PIPES.		
30000	Feet of ½ in. wrought iron tubes, including laying and fixing .... at 6*d.*	750 0 0	
35000	Feet of ¾ in. do. do. at 8*d.*	1,166 13 4	
30000	Do. 1 in. do. do. at 10*d.*	1,250 0 0	
12000	Do. 1½ in. do. do. at 1*s.* 3*d.*	750 0 0	
15000	Do. 2 in. cast iron pipes for ditto, including laying and fixing at 10*d.*	625 0 0	
15000	Feet of 2½ in. do. do. at 1*s.*	750 0 0	
22000	Do. 3 in. do. do. at 1*s.* 4*d.*	1,466 13 4	
8000	Do. 3½ in. do. do. at 1*s.* 6*d.*	600 0 0	
15000	Do. 4 in. do. do. at 1*s.* 9*d.*	1,312 10 0	
			8,670 16 8
	V.—ENGINEERS' EXPENSES and Commission (say)	—	9,000 0 0
	VI.—GENERAL EXPENSES during construction of the works, for salaries, wages, stationery, and other petty cash disbursements (say)	—	3,000 0 0
	VII.—INTEREST ON CAPITAL sunk during the construction of the works at 5 per cent.	—	5,000 0 0
	VIII.—FUND FOR CONTINGENT and unforeseen outlay and expenses	—	5,000 0 0
	IX.—PAYMENT TO VENDORS for the district concession in the patent rights as agreed	—	10,000 0 0
	X.—COST OF PROMOTION, legal charges, advertisements, printing, &c., &c.	—	2,000 0 0
	Total Cost		£ 198,285 3 8

THE BIRMINGHAM COMPRESSED AIR MOTIVE POWER SUPPLY COMPANY.

ESTIMATED YEARLY INCOME AND EXPENDITURE.

INCOME.	£	s.	d.
Estimated Income on (say) 2,500 indicated HP. at the rate of £8 per HP. per annum, giving the Consumer an advantage of 20 per cent., as shown at Page 6	20,000	0	0
Estimated Income on (say) 2,500 indicated HP. for special applications, for which a higher rate can be charged, averaging (say) £10 per HP. per annum	25,000	0	0
Total Income	£45,000	0	0

EXPENDITURE.	£	s.	d.
Coal for 8,400 indicated HP. at work during 2,763 day-hours, and 2,800 indicated HP. at work during 2,456 night-hours, at 2 lbs. per indicated HP. per hour, about 27,000 tons at 6/-	8,100	0	0
Manager's Salary	600	0	0
Chief Engineer's Salary...	500	0	0
One Assistant Engineer and Draughtsman	150	0	0
One First Engineer, for Engines and Boilers	200	0	0
One Second Engineer ,, ,, ...	150	0	0
Two Third Engineers ,, ,, ...	200	0	0
One Foreman and Two Fitters in Mechanics' Shop ...	300	0	0
Four Foremen Stokers at 30/-, and 10 Ordinary at 25/- p. week	962	0	0
Two Engine Drivers for Coal Elevators, at 25/- per week ...	130	0	0
Head Book-keeper and Cashier	350	0	0
Three Clerks at £2 per week	312	0	0
Two Collectors of Air Rent at £2 per week	208	0	0
One Stores and Timekeeper, and One Night Watchman ...	130	0	0
Messengers and Yardmen (say)	208	0	0
Repairs of Engines Boilers, Pipes, and Buildings	2,000	0	0
Renewal of Boilers Engines, &c....	3,000	0	0
General Stores—Oil, Tallow, Packing, &c.	800	0	0
Office Expenses, Stationery, Postage, &c.	200	0	0
Legal and Miscellaneous Expenses—Auditors' Fees, &c. (say)	500	0	0
Rent, Rates and Taxes, Lighting, &c.	1,500	0	0
Directors' Fees (say)	500	0	0
	£21,000	0	0
Nett Profits	£24,000	0	0
	£45,000	0	0

N.B.—The above shows a Profit of 12 per cent. on the Capital Expenditure of about £200,000, as shown by the Estimates on page 52, but the Coal Expenditure in this estimate is given at the maximum rate. There is no doubt, however, that with such large engines the consumption would be below 2 lbs., reducing the Annual Expenditure to less than £20,000. By re-heating the air on the consumer's premises, and a partial substitution of Town refuse for coal fuel, this Expenditure may be reduced to under £15,000, showing a profit of about 15 per cent.

APPENDIX.

Extract from a "TREATISE ON TRANSMISSION OF POWER," *by* Mr. Robert Zahner, C.E.

(Published by D. Van Nostrand, New York.)

Various modes of transmitting power. Objections thereto for long distances.

"For transmitting power to great distances shafts, belts, friction-wheels, and gearing are clearly out of the question. The practical incompressibility and want of elasticity of water renders the hydraulic method unfit for transmitting regularly a constant amount of power; it can be used to advantage only where motive power, acting continuously, is accumulated and applied at intervals, as for raising weights, operating punches, compressive forging, and other work of an intermittent character, requiring a great force acting through a short distance. . . .

Objections to steam power.

"In carrying steam to great distances very important losses occur from condensation in the pipes, especially during cold weather. The wear and

Objections to electric power.

tear of cable lessens the advantages of the telodynamic transmission; steep inclinations and frequent changes of direction of the line of transmission often exclude its adoption; while it is entirely excluded when it is rather a question of distributing a small force over a large number of points than of concentrating a large force at one or two points.

Compressed Air the only universally applicable power.

"**Compressed air is the only general mode of transmitting power; the only one that is always and in every case possible, no matter how great the distance nor how the power is to be distributed and applied.** No doubt as a means of utilising distant, yet hitherto unavailable, sources of power, the importance of this medium can hardly be over-estimated.

Compressed Air a storer of power.

"But compressed air is also a storer of power, for we can accumulate any desired pressure in a reservoir situated at any distance from the source, and draw upon this source of energy at any time, which is not possible either in the case of steam, water, or wire-rope.

Convenience as regards pipes.

"Larger supply pipes are required for steam or water transmission; the inconveniences resulting from hot steam pipes, the leakages in water pipes, the high velocities required in telodynamic transmission are all

Independent of differences of level, &c.

without their counterparts in compressed air transmission. Compressed air is furthermore independent of differences of level between the source of power and its points of application, and is perfectly applicable, no matter

Conduces to coolness and purity of the atmosphere.

how winding and broken the path of transmission . . . . compressed air, besides being free from the objectionable features of steam, possesses properties that render its employment *conducive to coolness and purity in the atmosphere into which it is exhausted.*"

"There is every reason to believe that compressed air is to receive a

Diminished cost.

still more extensive application. The diminished cost of motive power when generated on a large scale, when compared with that of a number of separate steam engines and boilers distributed over manufacturing districts, and the expense and danger of maintaining an independent steam power for each separate establishment where power is used, are strong reasons

for generating and distributing compressed air through mains and pipes laid below the surface of streets in the same way as gas and water are now supplied. **Especially in large cities would the benefits of such a system be invaluable;** no more disastrous boiler explosions in shops filled with hundreds of working men and women; the danger of fire greatly reduced, a corresponding reduction in insurance rates, an important saving of space cleanliness, convenience and economy. We say economy, for there is no doubt that a permanently located air-compressing plant established on a large scale, and designed on principles of true economy and not with reference to cheapness of construction, would supply power at a much less cost than is supposed.

Specially suited for large cities.

Economy.

"Compressed air is also applied in a variety of other ways—in signalling, in propelling torpedo boats, in ventilating large and confined spaces, in driving machinery in confined shops, in sinking bridge caissons. The pneumatic dispatch system, the air brake, the pneumatic elevator and hoist, are further examples of its use."

Varieties of application.

A FEW FACTS ABOUT COMPRESSED AIR.

1. Compressed air is now widely used as a motive power. Its economical advantages, under suitable conditions, are well understood and admitted, and its application and uses very numerous and varied.

Compressed Air already proved and extensively used.

2. It has long been used for pumping, haulage, and other operations in mines, on a scale quite as extensive as would be presented by the streets of a moderate-sized town.

3. It can be conveyed in pipes for long distances and in various directions, with very little appreciable loss by friction, and with well-constructed joints the loss by leakage is very slight.

Can be carried long distances in pipes.

4. The Mont Cenis, St. Gothard, Hoosac, and other tunnels in Europe and America, afford examples of the economical employment, in connection with the use of rock-boring machinery, of pneumatic power generated by water or steam power at long distances from its point of application.

Employed in tunnelling, &c.

5. At the Hoosac tunnel, in Massachusetts, the air pressure at the air compressors was 62 lbs. to the square inch, while at a distance of nearly two miles up the tunnel the pressure was only reduced to 60 lbs. when the drills were in full working.

At Hoosac tunnel.

6. At the St. Gothard tunnel the loss of pressure by friction and leakage was carefully tested. At the South end, with an absolute pressure of 5·7 atmospheres in the receiver, the pressure at the forehead, through a pipe 1 mile 15 yards in length, and 7⅝ in. in diameter, was only reduced to 5·5 atmospheres, or to **96½ per cent.** of the head, whilst eight perforators were actually at work and expending collectively 64 cubic feet of compressed air per minute.

At St. Gothard's tunnel.

To ascertain the amount of *leakage*, the receivers and pipes were filled, the valves closed, and the compressor and rock-drills stopped. At the end of **twelve hours** the pressure had only fallen from 6 atmospheres absolute to 5·8 atmospheres, or to **96⅔ per cent. of the original pressure.**

Leakage at St. Gothard.

Friction and Leakage at St. Gothard.

In the middle of the tunnel, through a length of pipe of about 3¾ miles, the pressure was reduced, when the perforators were at work, from 6 atmospheres absolute to 5·7 atmospheres, or to **95 per cent. of the original pressure.**

Friction of Air compared with water.

7. Given a pipe one mile long, and 12 inches diameter, then, calculated by Box's formulæ, the head required to pass—

(*a*)	WATER	at a velocity of	4 ft.	per	second,	would be 40·4 ft.	of water.
(*b*)	,,	,,	9 ft.	,,	,,	204·6 ft.	,,
(*c*)	AIR	,,	4 ft.	,,	,,	0·03 ft.	,,
(*d*)	,,	,,	9 ft.	,,	,,	0·15 ft.	,,

Thus showing that, as compared with water, the friction of air is as 1 to 1,336 about!

Improvements in Air compressing.

8. By recent improvements in Air-compressing Engines their efficiency has been greatly increased, and the losses formerly regarded as inseparable from the *production* of this motive power have been reduced to a minimum.

Economical sources of power.

9. In many cases power may be obtained to compress air for motive power and other purposes, either by **burning the ashpit and other refuse of towns as fuel,** or by water power, thus saving cost of fuel, and more than compensating for losses in compressing the air.

Compressed Air destroys organic germs.

10. It has been shown by Professor Tyndall, that compressed air destroys organic germs, a fact which adds a special value to it in its application to sewage.

High Pressure Air.

11. Compressed air has been used at extremely high pressures, as for instance in Marsh's apparatus for breaking down coal in place of using gunpowder, in which a pressure of 24,000 lbs. to the square inch has been obtained.

Driving tram cars.

12. We have now in England and America tram cars carrying air at pressures as great as 2,000 lbs. per square inch, and moving a weight of several tons for 20 miles without renewal of the air charge.

Pneumatic despatch.

13. For many years a great portion of the London and the Paris District Telegraph and Postal work has been carried out by means of pneumatic tubes, through which small trucks containing despatches are blown along their course; and it was proved that the application of compressed air behind the trucks was more convenient and economical than suction at the receiving end of the tube.

Compressed Air brakes.

14. The fast trains on railways are now controlled by a continuous brake, actuated by a small air compressor on the engine, connected by a tube with every carriage, and the application has been carried so far that the same source of compressed air forms a means of communication between passengers, guard and driver, and also drives air through a reservoir of volatile hydro-carbon and thence into the carriage lamps, where it burns with a steady luminous flame, obviating the expense, delay and inconvenience of oil lamps, and their cleaning and changing.

Already applied in Paris.

15. In Paris, Compressed air is applied to work clocks, and the system is now being extended so as to work various kinds of machinery.*

Used in sugar refining and chemical works.

16. Compressed air is used in sugar refineries in connection with the *Monte-jus*, for lifting or forcing the semi-fluid syrup through strainers; also

* *See extract from "Globe," January 13th, 1883, at page 57.*

in chemical works for raising liquids which would be injurious to metal pumps.

Isaac Shone's pneumatic sewerage system.

17. Compressed air is now used at Eastbourne, Warrington, and Winchester for the discharge of sewage in those towns on Isaac Shone's Pneumatic sewerage system. At Eastbourne one of the sewage collecting and discharging stations is distant two miles from the air compressing station. Similar works have been approved of by the Local Government Board for the West London District Schools, and schemes have been submitted to, and are in course of being sanctioned by the Worthing, Finchley, Fenton, Mexborough, Sheerness, and Southampton Sanitary Authorities. This system has also been selected by the Borough Engineer of Durban, Natal, for the drainage of that town.

The following Extract from the GLOBE *Newspaper of January 13th,* 1883, *will give some idea of the progress that is already being made in the application and distribution of Compressed Air Motive Power:—*

"COMPRESSED AIR.

"Although the grand programme relating to works of public utility in France has been modified considerably of late, and their execution retarded by various causes which it would be long to enumerate, there has been no hitch in carrying out that part of the scheme which is concerned with the supply of compressed air for practical uses in the capital. It will be remembered that the original scheme included the working, by means of this agency, not only of clocks in the municipal buildings and offices, and in private houses, but also of electric lighting and of various motors for commercial purposes. Of these designs, the first-mentioned is the only one which has yet been realized to any large extent; but in this at any rate, namely, the effecting by the new power a distribution of force to the Parisian clocks, rapid progress is being made. Before the end of last year it was announced that no fewer than 6,000 clocks of various kinds, chiefly exposed to public view, were regulated in this way in three of the most populous *arrondissements* of the capital. A short delay will now suffice to establish the system in all the other districts, including the whole area within the fortifications, and even to extend it to some of the principal suburbs. Already about 600,000 feet of conduits have been laid, and one at least of the branch stations for storing the air has been completed and fitted up for use. The principal works at which the compressing process is performed are situate in the Rue Ménilmontant, and occupy an area of about 7,000 square yards. The air is compressed to a normal pressure of six atmospheres, but the force actually employed in the local service is not so much as half of this. When the project has been fully worked out, the whole city will be supplied with conduits and accumulators, and the motive force will be supplied to those who require it at a set price, in much the same way as gas and water, but, as may easily be supposed, under different conditions to those which govern the supply of the latter necessary to unlucky Londoners."

REPORT

ON THE

PROPOSED

BIRMINGHAM COMPRESSED AIR-POWER COMPANY,

BY

PROFESSOR HENRY ROBINSON, M. INST. C.E.

I have directed my attention for many years to the question of the transmission of power to distances, and to the more economical distribution of power to consumers, in the way proposed to be carried out at Birmingham by means of compressed air, and I am of opinion that the scheme will be most beneficial to the district supplied, and profitable as a commercial undertaking.

The principle that is involved in this work is one which recommends itself on general grounds to the judgment of those whose interests require the production of a motive power in as cheap and convenient a form as possible.

By concentrating at one point the engine power necessary to actuate the machines and appliances of various traders over a large area, the consumers of power are able to dispense with their independent steam engines and boilers, and the skilled labour required to work them, with a saving in the cost of working, and with the advantage of having the space occupied by them available for other purposes, and also with a diminution of fire risks.

This principle (which I have termed "power co-operation"), although long recognised as excellent, has only of recent years been put into operation. The first example was The Hull Hydraulic Power Works (of which I was the engineer) where water pressure was employed as the motor most suitable to the various appliances which had to be worked at that commercial centre. Other towns are following in the same direction.

Most of the Dock and Railway Companies distribute the power required for their purposes over large areas, and from one or more centres, in the way suggested, with this difference, that in the case of the Companies the appliances are under one ownership, whilst in the other case the appliances are under several ownerships.

The power mains of the Dock and Railway Companies are laid chiefly under their own roads, whereas to supply power over an area in a town the consent of the local authority is required to the interference with the public streets. This might appear to constitute a difficulty, but in the case of the

Corporation of Hull I not only experienced no difficulty, but I received the most intelligent assistance and co-operation, although the streets under which the power mains were laid were busy thoroughfares, and in places were very narrow.

Considering that the trade of a town will be benefitted by any arrangements tending to a diminution of working expenses and cost of production, it is not likely that the Corporation of Birmingham will raise a difficulty, but will rather lend every support to a scheme which must prove advantageous to the town.

The motive power that can be distributed by mains may be either compressed air or water, and the suitability of the power to a district depends upon the nature of the machines and purposes to which it is to be applied in that district. The consideration of the circumstances which govern the adoption of a form of motor was entered upon fully by me in a paper on the "Transmission of Power to Distances," which I read before the Institution of Civil Engineers in 1877.

At Birmingham I consider compressed air to be the most suitable motor, inasmuch as it is required to be applied chiefly to machines working expansively, by which the elastic properties of compressed air are utilized.

The data which are now available with reference to the transmission of compressed air, extend over a wide field of practical experience, and the cost of production, allowances for loss in production and transmission, and methods of application, are now matters of common knowledge.

It is an ascertained fact that air compressors, as constructed at the present time, produce a much higher co-efficient of useful effect than those of even a few years back. This enables compressed air to be economically converted into a motor under very favourable conditions for convenient and cheap utilization by the machines.

The application of compressed air to apparatus working expansively enables all the advantages to be realized which have been referred to as obtaining under a power co-operation system. Only such power need be consumed and paid for as is required for the purposes of the works. When the compressed air has exerted its useful effect, and passes out of the machine which it has worked, it fulfils the further useful function of improving the atmosphere around. This is a matter of practical advantage in workshops, and serves also to improve their hygienic condition.

The concentration of the power producer at a centre, and the consequent abolition of all the small existing boilers and chimneys, will materially tend to smoke abatement.

Whilst compressed air can be conveyed from the place where it is compressed to the engines and machines worked by it, without the loss which is experienced in the case of steam, the machines to which it is supplied should work with the same economy as steam. The loss in

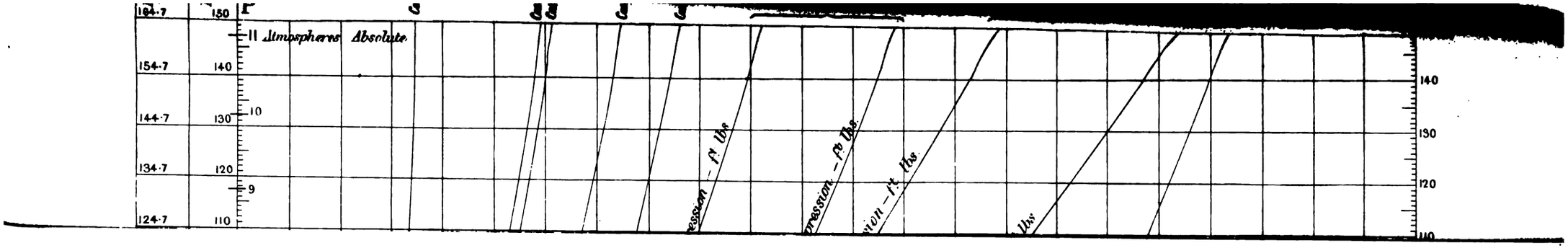
transmission compares favourably with that of other motors when elasticity of the air and the attendant advantages accruing therefrom considered.

The carefully compiled data before me with reference to the proposed to be supplied with compressed air in Birmingham, and details of the mode of carrying out the works, recommend this sch to my judgment as one deserving of the support of the Corporation, an likely to prove a commercial success.

HENRY ROBINSON, M. Inst. C. E.,

7, Westminster Chambers, S

22nd February, 1883.


154·7
144·7
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11 Atmospheres Absolute
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COMPRESSIN
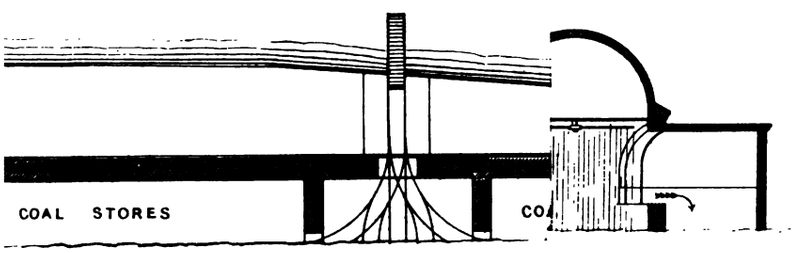
PLATE Nº I.